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THE BRIGHTNESS OF ROAD SURFACES UNDER ARTIFICIAL ILLUMINATION

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535.241.44 : 628.971.6

In this article [1]) it is shown that the distribution of brightness of the road surface either in the wet or the dry condition has no constant relation to the distribution of the illumination. The reason for this is that the parts of the road surface at greater distances from the observer are viewed at smaller angles to the surface. A continuous layer of water on the road surface makes the designing of a good road lighting system impossible. Methods are indicated for determining the reflective properties for the dry and the damp condition (brightness coefficients). A completely worked-out diagram of brightness coefficients is given for one road surface. Several conclusions about the requirements to be made of the light distribution of the sources are discussed on the basis of the distribution of the brightness coefficients.

In a previous article in this periodical [2]) it was pointed out that the distribution of brightness over the surface of a road is very dependent upon the nature of the road surface and its condition of dryness or wetness.

The divergent characteristics of road surfaces are more pronounced the smaller the angle at which they are observed. This means chiefly that great differences between the various kinds of road surface (and the various degrees of wetness) may be expected, when parts of the road are viewed which are relatively far away from the observer. These parts of the road are of extremely great importance in visibility on the road. It has been shown by various investigations [3]) that with a fixed lighting system the objects and persons on the road are usually only seen as dark silhouettes against the light background of the distant illuminated road surface.

For fast traffic an obstacle must be observed at a distance of from 75 to 100 metres. The part of the road which can serve as background in this case is therefore 100 to 150 metres in front of the observer. At a height of the eye of 1.50 metre, and with a level road, that part of the road is therefore observed at an angle of 0.5 to 1° to the road surface (at an angle Ψ of 89° to 89.5 to the normal to the surface).

The lighting installation must give a light such that at directions of vision for which $\Psi = 89$ to 89.5° the brightness of the surface of the road is distributed fairly uniformly. This requirement must be satisfied in dry as well as wet weather; in the latter case the difficulty is greatest because it is just at the above-mentioned angles of observation that the reflective properties of the road surface are very variable with the degree of wetness.

In order to show that at these angles of vision we may expect very remarkable effects, we shall first deal with a degree of wetness of road surface which fortunately cannot occur in the case of a great many roads, and in other cases only occurs for a short time. Afterwards we shall draw certain conclusions about the distribution of brightness on a road.

The road surface covered with a continuous layer of water

It is well known that a continuous layer of water on the road surface acts like a mirror surface. When one looks at puddles on the road which are only a few metres away from the observer, images are seen which are nowhere near as bright as the objects whose images they form. The greater the distance between the observer and the puddle, however, the brighter the images.

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[1]) Most of the data in this article are taken from "Light Reflection by Road Surfaces" by J. Bergmans, dissertation, Delft, June 1938, published by Waltman of Delft. This dissertation is written in the Netherlands language, while a short resumé in English is given at the end of each chapter.

[2]) G. B. van de Werfhorst, Philips techn. Rev. **2**, 239, 1937.

[3]) This was first remarked upon by Millar, I.E.S. Trans. **5**, 653, 1910.

This practical experience corresponds exactly to the theory about the reflection at non-conducting surfaces (glass, water, stone, etc.). This type of reflection takes place according to Fresnel's formulae and may be illustrated in a simple way as is done in *fig. 1* for water.

From Fresnel's formulae it may further be seen that the coefficient of specular reflection is the same for two corresponding angles Ψ and u (see sketch of path of rays in fig. 1). In other words just as large a percentage is reflected when the light passes through the air and is incident on the water surface, as when it comes from the water and is incident on the lower side of the water surface, if the angles Ψ and u are corresponding angles.

This has been expressed graphically in a simple way by plotting as abscissae the angles u corresponding with Ψ. The graph thus indicates ϱ_Ψ as well as ϱ_u.

What is now the brightness of an inundated piece of road surface seen from a distance of 75 to 150 metres?

Let us consider *fig. 2*. From all possible directions (h, g) light may fall upon the surface of water. According to Fresnel's formulae more or less light will be reflected at the surface depending on the angle at which the light is incident on it. A large percentage of this light will penetrate into the layer of water, reach the road surface, be reflected there and again emerge into the air through the surface. Because of the fact that the reflecting power of the particles of which the road surface is built up decreases sharply when they are enclosed on all sides by water, only a small amount of light will be reflected by these particles into the layer of water.

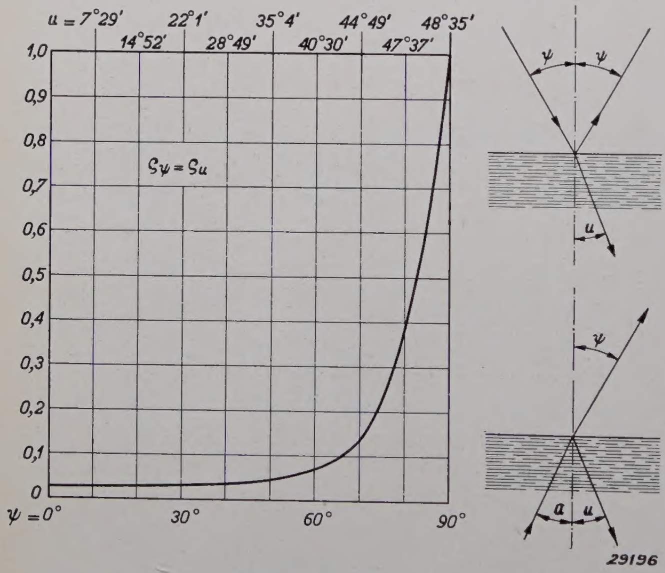

Fig. 1. Reflection coefficient ϱ_Ψ for light falling on a water surface at an angle Ψ as a function of Ψ. The same curve gives the reflection coefficient of a ray which strikes the water surface from below at an angle u, as a function of u provided the angles Ψ and u are corresponding angles (see sketch above the diagram). This is expressed by noting the angle u as abscissa at the top of the diagram.

For $\Psi \rightarrow 90°$ the reflection coefficient becomes equal to 1. If the light strikes the inner side of the water surface from below at such an angle u that the emergent ray would leave the surface in a practically horizontal direction, then it is also practically completely reflected and cannot emerge.

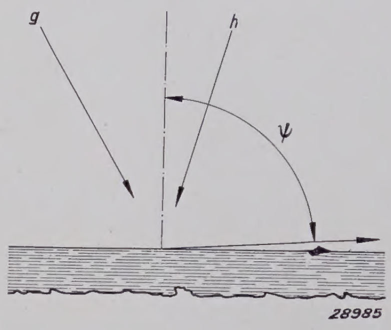

Fig. 2. In the direction of observation $\Psi = 89°$ only that light is observed which has been reflected at the water surface, and thus satisfies the conditions of specular reflection. Light which has penetrated into the water is practically unable to emerge at an angle of 90° (see under fig. 1).

This decrease in the reflection of the particles of the road surface enclosed by water plays a much less important part than the second reflection of the light at the inner surface of the water boundary. The brightness of the surface in observation at a great distance is determined by the amount of light which is directed toward the eye of the observer and therefore which leaves the surface of the water at an angle Ψ = 89 to 89.5° (see fig. 2). It may be seen from fig. 1 that the reflection at the inner surface of the water is 90 per cent for an angle Ψ = 89°, and 95 per cent for Ψ = 89.5°.

It may therefore be seen that, of the already smaller amount of light reflected from the road surface, almost none of it can reach the eye of the observer at a great distance. Therefore no matter how strongly an inundated road surface is illuminated from all possible directions, when the angle of vision Ψ = 89 to 89.5° the road surface will always remain absolutely dark. The only way of making the surface appear bright is to have the light incident at an angle equal to the angle at which it is observed.

In this connection we should like to mention a very nice test which can be carried out with simple means.

A light-coloured slab f (see *fig. 3*) is provided with an inscription. At the same time a vertical board d with an inscription in mirror script is set up at the end of the slab. The whole surface of the slab is covered with water. We observe from the directions a, b and c which make angles

Ψ of 60°, 75° and 89°, respectively, with vertical. Fig. 4*a*, *b* and *c* show what one sees at the directions of observation *a*, *b* and *c* respectively.

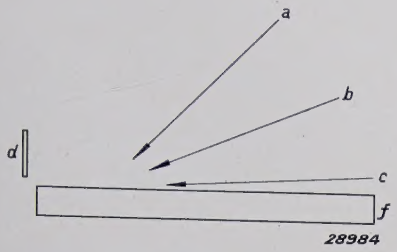

Fig. 3. Comparison of the reflective power of a wet slab upon observation from the directions *a* (60°), *b* (75°) and *c* (89°). The word STOP is written on the slab. On the board *d* there is an inscription in mirror script. Fig. 4 shows how the board is reflected better and better with increasing angle of incidence, while the inscription on the slab itself becomes vaguer and vaguer.

These photographs illustrate clearly how the road surface acts more and more as a perfect mirror upon increase of the angle Ψ.

Therefore although an inundated road surface does not at all possess the properties of a mirror for all possible directions of observation, it follows from the above explanation that when it is viewed from a great distance the road surface begins more and more to act as a perfect mirror.

Because it is just these directions of observation which are of primary importance in fast traffic, the warning contained in the twelfth conclusion, fifth question, of the 8th International Highway Congress (The Hague, June 1938) is very much to the point.

The conclusion was as follows:

12. *The road surface should be so constructed as to prevent so far as possible the formation of a water layer, which tends to make the road surface act as a mirror, producing excessively bright, narrow streaks, causing glare and thus reducing visibility.*

How does the road surface reflect when there is no layer of water?

We have seen above that an inundated road surface can never be quite satisfactorily illuminated, and we shall leave this least favourable case out of consideration in the following. Even with a dry surface, however, or with a surface which is damp but not inundated, the reflective properties which must be taken into account in planning a lighting installation are far from simple. Even with apparently diffusely reflecting road surfaces the intensity of reflection in a direction practically parallel to the road surface is found to deviate very much from Lambert's law.

In order to form some idea how the reflection takes place on a dry and a damp road surface, it is advisable to examine several kinds of road surfaces under a binocular mircoscope. Two types of structures which will be encountered are show nin *fig.* 5. From these and other types of surface which

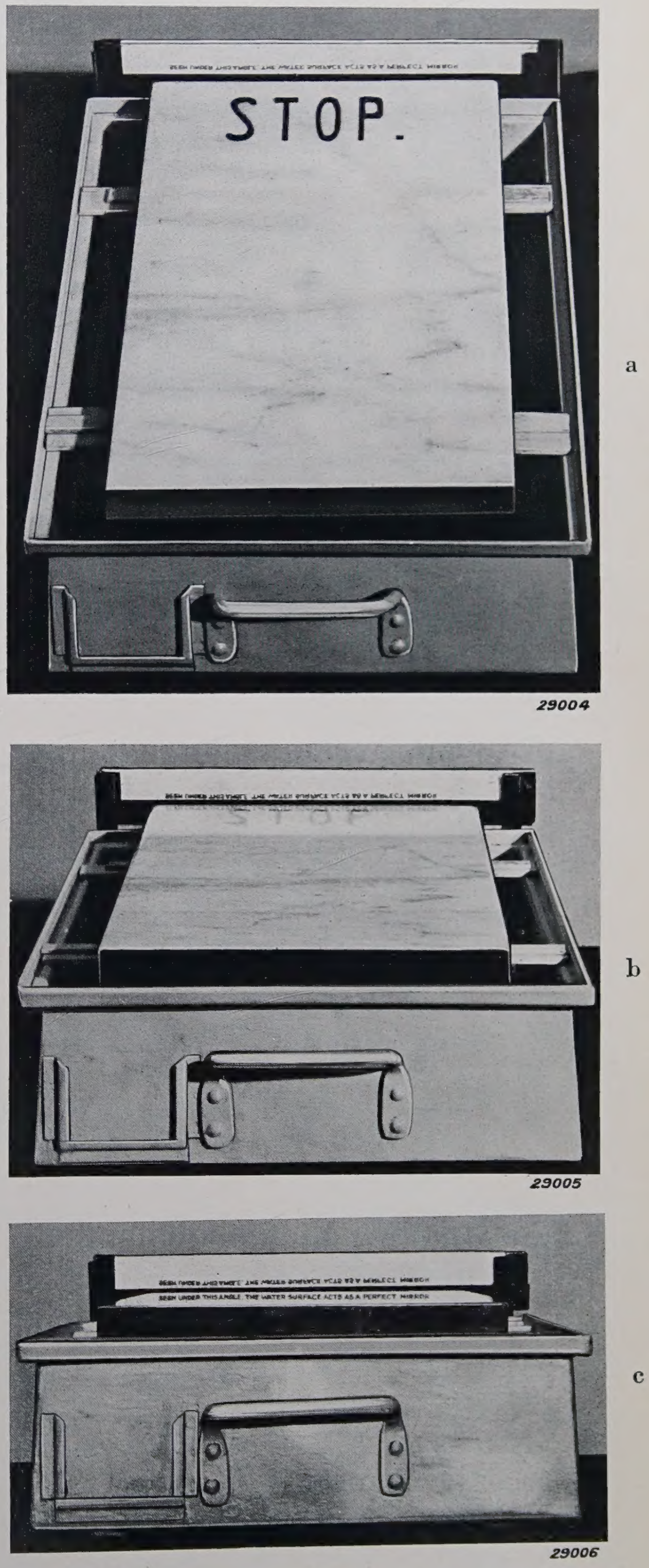
STOP.
a
29004
b
29005
SEEN UNDER THIS ANGLE THE WATER SURFACE ACTS AS A PERFECT MIRROR
c
29006

Fig. 4. Reflection by a road tile in the arrangement shown in fig. 3. The three photographs refer to the directions of observation *a*, *b* and *c*.

we examined microscopically we obtained the following general impression.

Road surfaces are fairly rough. One of the main causes of the pitting of the surface is the breaking out of bits of stone. The elevations are in many cases places where a piece of hard stone lies directly under the surface or projects slightly above it.

Due to the pits and the elevations the light which falls on the road surface from a certain direction will be spread in many directions, even if it is reflected specularly by the individual particles of the road surface as is the case to some extent. Some particles themselves on the other hand exhibit a spread reflection [4]).

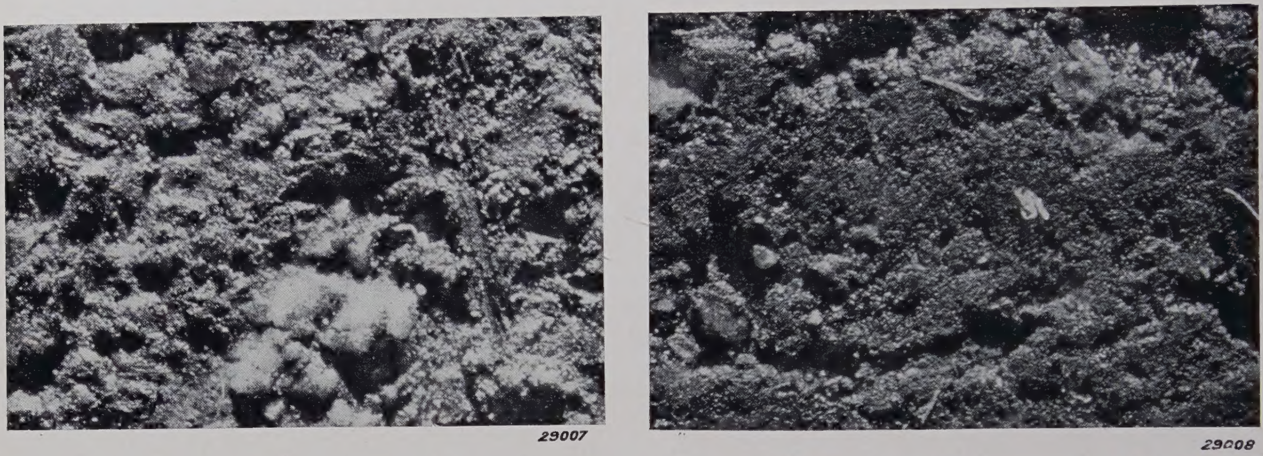

Fig. 5. Photomicrographs (enlarged 20 times) of road surfaces which have been in use.

a) Highly coarse asphaltic concrete with coating layer of "sand-clinker sheet", taken from the road between the Hague and Delft. This road surface shows many small transparent crystals which are not clearly seen in the photograph.

b) Fine asphaltic concrete on binder coarse taken from the road between Amsterdam and Haarlem. The road surface is dark and fairly smooth, aside from pitting and grooves.

The latter particles usually appear grey in colour; the light penetrates into them to some extent, and its direction is so changed that the reflection is in many cases almost completely diffuse.

When such a piece of road surface becomes damp, a layer of moisture is drawn over all the component parts of the fine structure. This makes the spread reflection of many particles less, and specular reflection according to Fresnel's formulae occurs at the surface of all the particles (see fig. 1).

When the amount of water on the surface is increased there will be further changes. The water films become thicker and begin to fill up the spaces between the projecting particles. The water film thus no longer follows the outline of the particle but rounds it off, so that the radius of curvature of the water surface is greater than that of the original particle of the road surface structure. The normals which may be drawn to this rounded-off water surface deviate, however, much less from the normals to the road surface in the dry condition. In this way the well known shiny effect is obtained: more reflection with respect to normals near vertical and less with respect to the normals with a great deviation from vertical.

It is clear therefore that with regard to its reflective properties the road surface in the dry and the damp condition is intermediate between the completely diffusely and the completely specularly reflecting surface.

We shall now attempt to characterize this state of reflecting power more closely by beginning with the two limiting cases, namely, completely diffuse and completely specular reflection.

Characteristic difference between completely diffuse and completely specular reflection

In the illumination of a completely diffusely reflecting surface the brightness which is reflected by that surface in any given direction is proportional to the illumination.

Let ϱ_d be the reflection coefficient of such a surface (ratio of the total reflected to the total luminous flux). Then the formula for the quotient q_d of the brightness B' (in c.p./sq.m*) to the illumination E (in lux) may be written as follows:

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[4]) We use the word "spread reflection" to indicate an intermediate condition between completely diffusing and completely specular reflection, when the intermediate state may not be described as: a certain percentage of the light completely diffused and a certain percentage completely specularly reflected.
An example for which the latter description is practically accurate is that of milk glass with a smooth surface. Most surfaces met with in practice having a matt lustre fall in the group which we here call "spread reflecting".

*) We have used "c.p./sq.m" and not the "stilb" (c.p./sq.cm) because:
1) The values, which are got for the brightness coefficients and which are already very low, increase with a factor 10^4;
2) in formula as *e. g* : $E = B \cdot \omega \cdot \cos \Psi$ the facter 10^4 disappears.

$$q_d = \frac{B'}{E} = \frac{\varrho_d}{\pi}.$$

The quotient q_d is called the **brightness coefficient for diffuse reflection.** For a perfectly diffusing surface it is a constant value with all combinations of directions of illumination and observation, and with all possible variations in the dimensions of the light source.

For a completely specular reflecting surface the quotient of the brightness to the illumination cannot be so simply given.

The specularly reflecting road surface is dark everywhere except in the direction of observation in which the mirror image of the light source is seen. The brightness B' of this mirror is determined only by the brightness B of the source, but is independent of the illumination on the road. The illumination E is not determined by the brightness of the source, but, at a given brightness of the source, it is proportional to the solid angle ω (see *fig.* 6) within which the light source is seen from a point on the road surface. The brightness coefficient therefore B'/E is not a property of the road surface alone but is inversely proportional to the solid angle ω for every point on the road surface, and therefore really has no significance in the characterization of the specularly reflecting road surface.

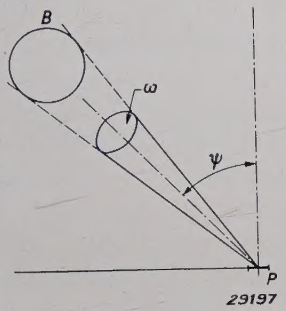

Fig. 6. The intensity of illumination of the point P on the road surface is $E = B\,\omega \cos \Psi$.

Spread reflection

Since spread reflection is an intermediate condition between diffuse and specular reflection, it may be expected that here also the brightness coefficient will not depend upon the direction of illumination and observation alone, but also upon the solid angle within which the light source is seen from a point on the road surface. It must here be assumed that the light sources continue to give mirror images — although not very sharp ones — in the spreading surface, and that the brightness of these mirror images increases when the light source (while retaining the same distribution of light) is decreased in size. When the apparent size of the light source becomes smaller, however, than the lack of sharpness of the mirror image, further decrease in size will give practically no change in the mirror image, and the brightness of the mirror image will then no longer increase.

For light sources smaller than this limit, there is therefore again a well defined brightness coefficient which depends only upon the directions of illumination and observation, and which is independent of the size of the light source.

It is clear that this limit will be the more quickly reached, *i.e.* will occur with a larger light source, the stronger the spreading of the reflected light.

A road surface which has a well-defined brightness coefficient with the ordinary dimensions of the sources of light for street lighting, is considered widely spread reflecting.

From measurements carried out by the author [5]) it was found that road surfaces in dry and moderately damp conditions may be considered widely spread reflecting surfaces. This is very important, because for that reason it has become possible to determine a value of q for every combination of directions of illumination and observation, and to discuss the properties of a road surface with the help of such a relation.

Results of measurements

In *fig.* 7 are given the lines of constant brightness coefficient for the dry condition (continuous lines) and for the reproducible damp condition (dotted lines) measured by us of the road surface of the road between the Hague and Delft (see photomicrograph fig. 5*a*).

In this drawing the camber of the road has been taken into account. The camber of modern roads is no longer rounded, but has more the shape of a roof. From the middle of the road the surface slopes toward both curbs with a slope of 1 : 50. Because of this a discontinuity in the course of the iso-q

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[5]) See the dissertation of the author, page 80. It was shown by experiment that the distribution of brightness of dry road surfaces does not change if the measurements are carried out first with a light source of such dimensions that the ratio: diameter of light source to height of mounting corresponds to the maximum ratio which ordinarily occurs in practice, and then with a light source which is 250 times brighter and whose solid angle ω is thus $^1/_{250}$ of the solid angle used in the first measurement. In order to carry out the same measurement on wet road surfaces a slab of the pavement was cut out and moistened in a definite reproducible way. The condition obtained in this way corresponds, according to our estimation, with the wetness which a road surface can retain for hours when there is a slight rain or heavy mist.

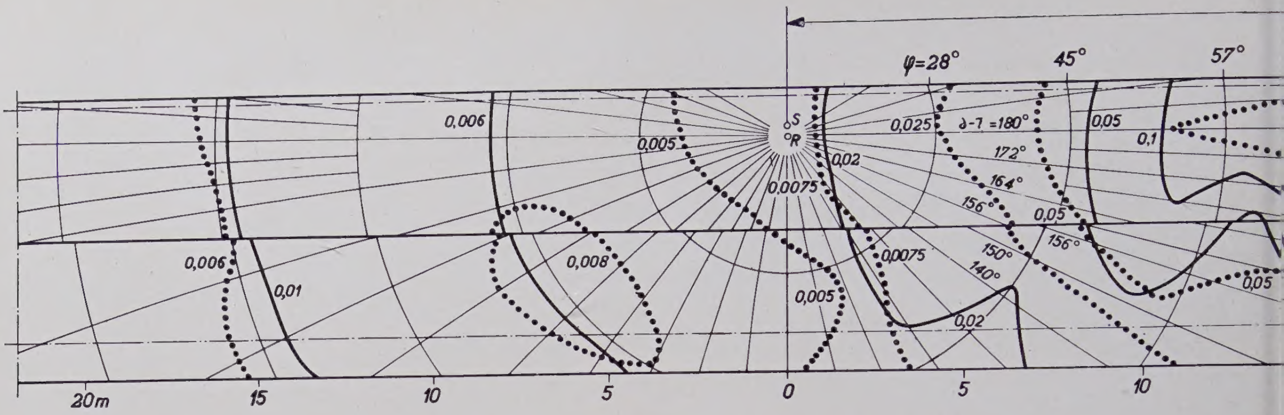

Fig. 7. Curves of equal brightness coefficient (iso-q curves) for a roof-shaped road (slope 1 : 50) 8 metres wide. Height of the light source 8 metres above the curb. The eye of the observer is at a distance of 100 metres from the lightsource and

curves may be seen at the axis of the road surface. The q values for different points of the surface, *i.e.* for different combinations of directions, are very divergent. In the diagram for the dry road iso-q curves may be seen for values of q from 0.006 to 1, while the q values for the damp road vary between 0.005 and 10.

Before we draw any conclusion from these iso-q curves about the brightness distribution with different light sources, it is first necessary to find out to what extent these iso-q curves are typical, not only for this road surface, but for all road surfaces. We were able to carry out similar measurements on brick, asphaltic concrete, granite setts and cement concrete road surfaces.

When the values from the measurements on all these different types of road surface are compared for the same combination of directions, a much smaller mutual variation is found than that for different combinations of directions measured at the same point of a single road surface.

On the basis of the figures obtained we may make the following statements.

In the dry condition the values of q for the same combination of directions for two points of different road surfaces are found to deviate from each other by not more than a factor of four.

On the other hand, also in the dry condition, the values of q for the same point on the road surface and for different combinations of directions, even with the most diffusing surface differ by a factor of more than fifty.

In the damp condition these values become greater and differences by factors of 8 occur between the different road surfaces. The different direction combinations of the same road surface then however differ very much more (by more than a factor of 2 000).

There is quite good correspondence between the iso-q curves of the different road surfaces. It is, however, not so exact that it is only necessary to provide the set of curves for one road surface with higher values in order to obtain the curves for another road surface, but it is such that the iso-q curves given in fig. 7 may be considered typical curves of a road surface in the two conditions of wetness measured by us. The surface referred to in fig. 7 was the darkest of all road surfaces which were measured. On an average the brightness coefficients have values which are higher by a factor of 2.5 [6]).

From the measurements on road surfaces in dry and damp condition which are the condition usually occurring, we may draw a general conclusion.

The isolux curves are still very often used as a basis for estimation in planning road illumination. It is then tacitly assumed that the illumination and the brightness observed by the road user have some constant relation to each other. The uniformity ratio of the strongest to the weakest illumination is considered by many persons, who must decide upon the carrying out of one system of illumination or another, as a ratio which, while perhaps not exactly corresponding to the ratio between the greatest and the least brightness, may nevertheless very well be used as a first approximation of this ratio. It is thus assumed that the value of q will be about constant.

From the fact that the value of q for dry road surfaces varies by a factor of more than 50 for

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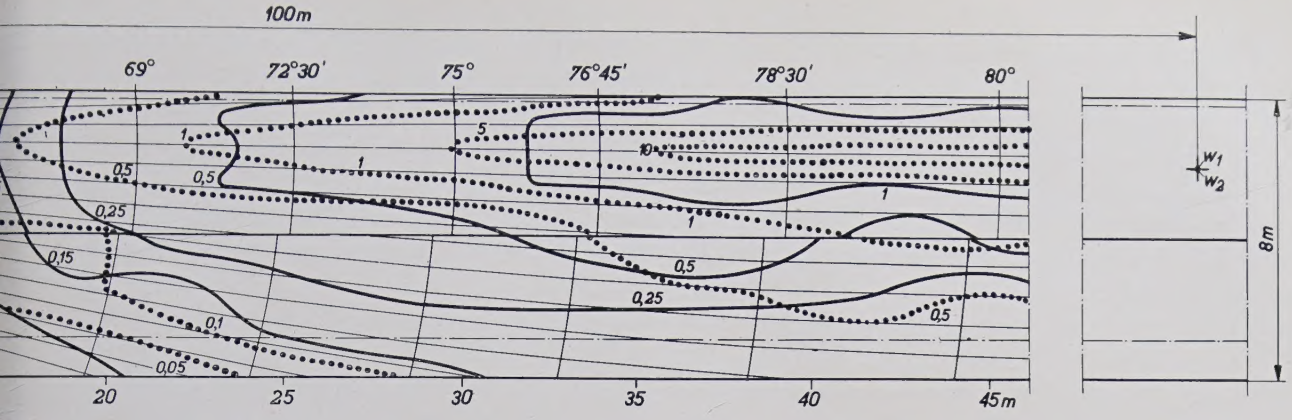
[6]) These relatively small differences between the types of road surfaces do not agree with the experience which we have of the behaviour of road surfaces during and after rain. *It must be concluded that road surfaces show the greatest relative differences when they are examined as to the amount of water which can be drained away per minute without any closed layer of water being formed.*



at a height of 1.50 metre above the surface of the road. Continuous lines indicate the dry condition, dotted lines the damp condition. The q values are measured on a section of the pavement of the road between the Hague and Delft.

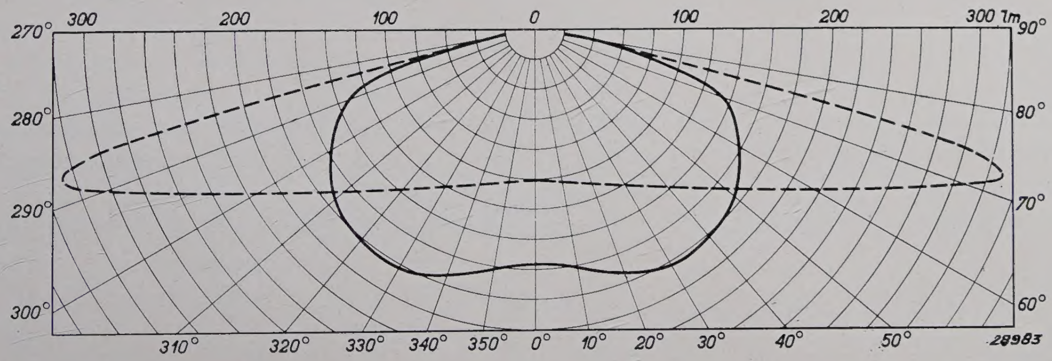
different direction combinations, and that in the damp condition this factor becomes greater than 2 000, *it is perfectly obvious that neither the isolux curves nor the uniformity ratio of the illumination have the slightest value in obtaining an impression of the distribution of brightness over the road surface.*

What practical use may be made of the brightness coefficients?

The illumination is the quantity which indicates the luminous flux consumed per square metre of road surface; the unit lux is one lumen per square metre.

Because the brightness coefficient indicates the relation between the brightness of the road surface and the luminous flux thereby consumed per unit of surface, this coefficient might be considered to be a measure of the efficiency of the road surface. This would be correct if the only purpose of road lighting were to raise the brightness of the surface as high as possible, and if the distribution of brightness were only of secondary importance.

For vision on the road, however, it is usually the other way round, and on a road where the average brightness is relatively low, but where the distribution of the brightness is good, it is usually easier to see obstacles than on a road where the average brightness is much higher and its distribution less uniform.



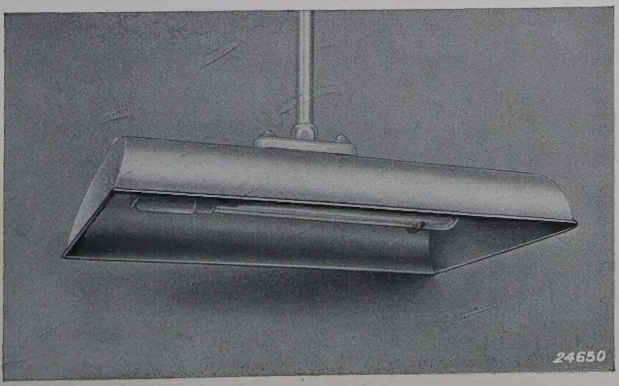


Fig. 8. Photograph (left) and curve of the light distribution (above) of the "Philora" fitting SORA 61001 for sodium lamps. This light distribution forms a compromise between the requirements of high efficiency and good uniformity of illumination. The dotted curve represents a less satisfactory light distribution.

When in order to obtain a greater brightness of the road surface more use is made of the higher brightness coefficients, it means that relatively more luminous flux is directed toward those points of the road surface for which the value of q is high. This will in most cases be the points which already possess a great brightness, so that the uniformity of brightness is thereby diminished. A relatively high luminous flux must therefore deliberately be directed toward points of the road surface with a relatively low brightness coefficient in order to avoid too great non-uniformity of brightness.

For the same reason great care must be taken in directing much light toward those points where the value of q varies very much in the damp and dry conditions. These are the points which lie between the light source and the observer at a relatively great distance from the source (see fig. 7).

Because of these requirements the distance which can be illuminated with a given height of the light source is limited. The avoidance of glare by the direct light from the light sources also necessitates a similar restriction in the length of road which can be served by each light source.

It is clear that important conclusions may be drawn from the distribution of the brightness coefficient in the dry as well as the damp condition, in connection with the height and spacing of the light sources. We shall return to this point in a later article.

The question of the degree of non-uniformity in brightness which is permissible is also a problem by itself. In dealing with this problem one must begin with the road seen in perspective, and with the dimensions, form and reflective power of the obstacles which must be able to be observed on the road surface. We intend also to make a further study of these perspective considerations.

A further study of what may or may not be permissible is also important because the reflective properties in the damp and dry conditions differ so much that one is never able to design an installation which has a satisfactory brightness and with which in the damp as well as in the dry condition the surface is seen about uniformly bright.

Discussion of the properties of a special fitting on the basis of known brightness coefficients

In *fig. 8* may be seen a photograph and the light distribution curve of the above-mentioned Philips fitting for sodium lamps "Philora"-SORA 61001. This fitting is usually mounted at the curb of the road on a bracket.

In *fig. 9* the distribution of the brightness is indicated for this fitting as observed from a point 100 metres from the pole (see fig. 6). The continuous curves (r, s and t) indicate for the dry condition respectively the brightness over the line joining the point directly under the light source with the position of the observer, the axis of the road and the boundary line of the road surface on the side opposite the light source. The dotted curves (u, v and w) indicate the brightness in the damp condition for the same lines on the road surface.

It may be seen from this figure that the fitting contributes very little to the brightness of those parts of the road which are farther away from the observer than the light source itself. This is illustrated most clearly in the damp condition. In the dry condition also, however, the brightness of points on the road which are more than 7 metres farther away from the observer than the light source itself may practically be neglected.

At a distance of about 28 metres from the light source on curve u (damp condition) is the point with the greatest brightness. At the same distance the brightness of the lines r, s and t is already considerably lower than the maxima occurring on these same three lines (dry conditions).

Various fittings have been put on the market which direct much light (three or four times the amount given by the "Philora" fitting mentioned above) toward these points farther away from the source. Distributions of light are then obtained as

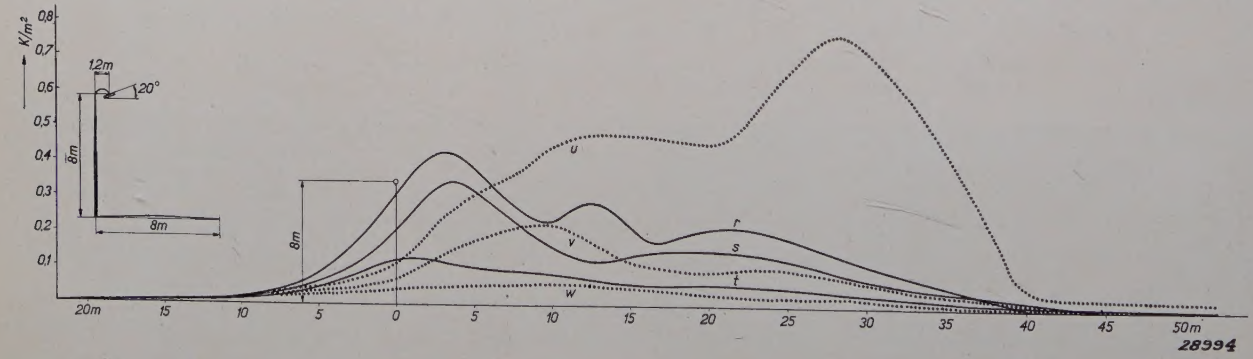


Fig. 9. Brightness distribution in the dry condition (continuous line) and in the damp condition (dotted line) over the road surface of fig. 7 upon employment of a lamp fitting according to fig. 8. The curves r and u refer to the line joining the point directly under the source and the observer; s and v refer to the axis of the road; t and w to the boundary line of the road on the side opposite to the light source.

indicated in fig. 8 by the dotted line. From fig. 9 it may be seen that this offers no difficulties for the dry condition (aside from the glare of the direct light in the eyes of the observer): the curves *r*, *s* and *t* may well be raised to three times their value at the cross section at about 28 metres from the light source without the brightness becoming disturbing for observation. For the damp condition, however, this is no longer the case. A brightness is then obtained which is about 40 times as great as that of any point lying on the side of the road opposite the light source. Such a great lack of uniformity is very disadvantageous to visibility on the road.

It may therefore be seen that with the fitting SORA 61001 a compromise has been made between, on the one hand, the greatest possible use of the higher values of the brightness coefficients, and, on the other hand, the avoidance of too great local brightnesses in the damp condition.

Higher illumination on the opposite side of the road

Until now we have spoken of light sources which distribute the light as well as possible along the lengthwise direction of the road. It was found that too much light must not be directed towards points on the road surface which lie on transverse cross sections at about 28 metres from the light source.

If now we consider the point in that cross section which lies on the opposite side of the road (see fig. 7) it will be seen that this point, even in the damp condition, does not have a high nor, fortunately, a very low brightness coefficient. Its value (0.1) even corresponds fairly well with the value in the dry condition.

Therefore when we conclude that for these greater distances from the light source the luminous intensity over the full width of the road must not be raised above the value which is given by the sodium lamp fitting SORA 61001, it does not mean necessarily that the luminous intensity toward points of the surface on the opposite side of the road may not be raised.

This fact offers a possibility for the improvement of the uniformity of brightness in the dry as well as the damp condition.

THE ELECTRO-ACOUSTIC INSTALLATION IN THE LEAGUE OF NATIONS PALACE IN GENEVA

by N. A. J. VOORHOEVE and J. P. BOURDREZ.

534.86

A survey is given of the system for the distribution and recording of sound which has been installed in the League of Nations Palace in Geneva. All components as far as possible have been housed in a central amplifier station, although this necessitated a greater number of connections than would have been necessary with a less centralized system. The advantage of the system used lies in the fact that it can more easily be operated.

Introduction

Among the assembly-rooms in the new League of Nations Palace on the Lake of Geneva there are two which had to be provided with electro-acoustic installations because of their great size, and for the sake of the publicity of the meetings to be held in these halls. They are the huge general meeting hall of the League of Nations: "Salle des Assemblées", the dimensions of which are 59 by 51 by 20 metres with seats for about 1550 persons, and a smaller assembly hall which is also equiped for cinema performances: "Salle des Commissions 12/13", with dimensions of 24 by 12 by 10 metres and about 400 seats.

The following objects had to be attained in a simple and reliable way with the apparatus to be installed:

1) Amplification of the intensity of speech in both of the rooms by the use of loud speakers, since the voice of a speaker cannot be heard sufficiently well in all parts of these rooms 1)).

2) Transmission of the speeches, not only to the League of Nations transmitters, but also to all other transmitting stations. The possibility

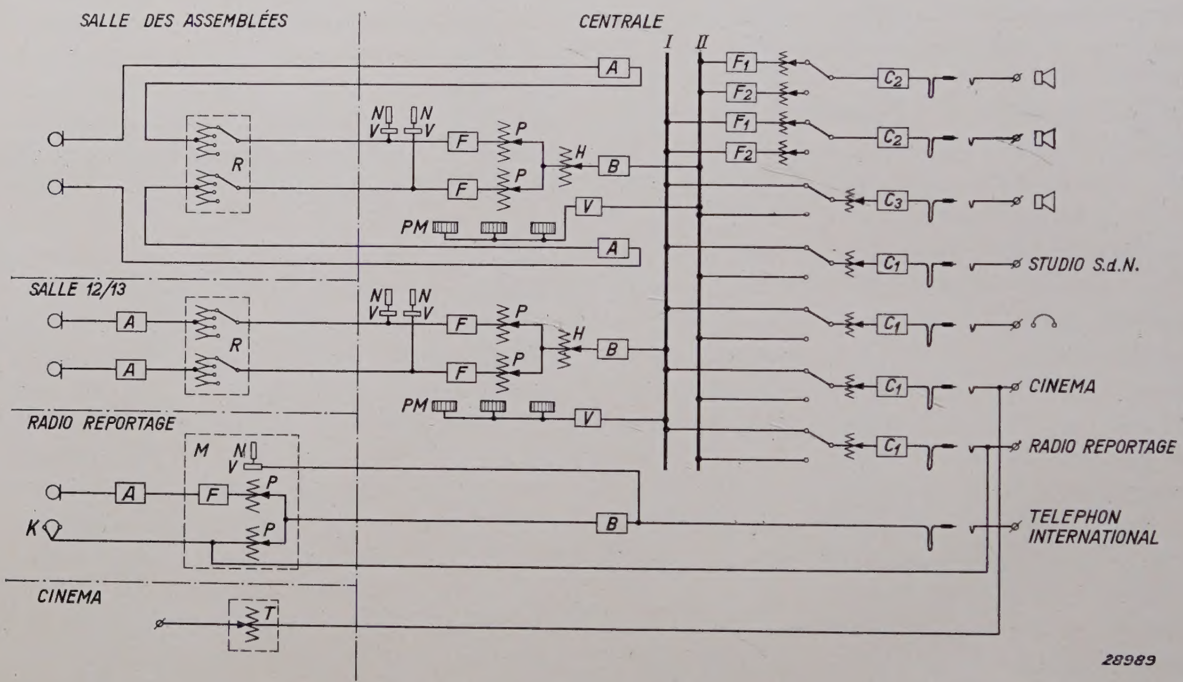


Fig. 1. Simplified diagram showing the principle of the amplifier installation (low-frequency part).

A = microphone pre-amplifier
B = intermediate amplifier
C_1 = separation amplifier
C_2 = power amplifier
C_3 = monitor amplifier
F, F_1, F_2 = filter
H = main volume regulator
P = mixing potentiometers
N = neon indicator
PM = programme meters
M = mixing cabinet for radio reporting
R = poste de régie
T = cabinet for making sound film connections and connections with other apparatus for sound recording.
V = amplifier for neon indicator and programme meter

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1) For further measures taken with the aim of improving the acoustics in the general meeting hall *cf.* Philips techn. Rev. **3**, 159, 1938.

had to be taken into account that different meetings might take place simultaneously in the two rooms.

3) Reproduction of the speeches by means of loud speakers in a great many other rooms of the building.
4) Radio reporting of the meetings, for which purpose a number of cabins were built in each of the rooms.
5) Recording of the speeches, either on sound film, when cinema films of the meeting are taken in the cabins for that purpose in each room, or by means of various apparatus for sound recording set up separately.

In this article several explanatory descriptions will be given, as well as particulars of general interest in installation technique about the electrical and mechanical execution of this installation.

The installation

In planning the project we were faced with a choice of two possibilities, either to built a separate system for each room or to combine the necessary apparatus for both rooms in one central control room. The latter solution was chosen in spite of the fact that a decentralized arrangement of the apparatus would have been easier to carry out technically, because of the great distance of 120 metres which separates the two rooms in the building. Centralized arrangement, however, offered, in addition to the most economical use of the necessary amplifiers, operating and control organs, the advantage that a minimum number of technically trained persons are necessary for operating the apparatus. These arguments more than make up for the necessity of certain special requirements of the cable connections due to the great distances to be bridged and the introduction of a simple signal arrangement which became necessary because the personnel responsible for the transmission is not stationed in the room itself. These two points are dealt with later on in this article.

In a very simplified form *fig. 1* gives the principle of the low frequency part of this transmission installation. It may be seen that only the indispensible parts of the installation are situated in the rooms themselves. To the left of the broken line are indicated the pieces of apparatus situated in the rooms; to the right of this line is the apparatus set up in the central station.

In both rooms a number of microphones of the table type (five in the "Salle des Assemblées", four in the "Salle 12/13") are installed on the speakers desk (*fig. 2*), and they correspond aesthetically with the decoration of the halls. In connection with the requirement that the quality of the reproduction may leave nothing to be desired ribbon microphones have been chosen.

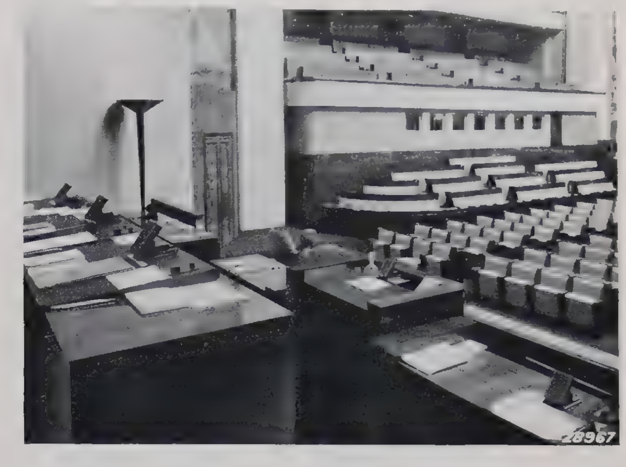

Fig. 2. Speakers rostrum in the "Salle des Assemblées" upon which the five ribbon microphones may clearly be seen.

Since ribbon microphones are not especially sensitive, difficulties might arise from interferences, if the relatively low output voltage of the different microphones should be regulated and mixed directly by means of potentiometers. It may be seen that pre-amplifiers (A) are first placed directly behind the microphones, which raise the level so high that the operation of the mixing potentiometers (P) can no longer cause audible disturbances.

As regards the microphones set up in "Salle 12/13", another possible source of disturbance must be avoided, namely the danger that audible interference voltages might be generated in the 120 metre long connection between these microphones and the amplifier station which is next to the "Salle des Assemblées". Such voltages might be caused by interference fields from other electrical connections in the building.

This difficulty could only be met by raising the level of the microphone voltages already at the beginning of this connection to a sufficient height, and, for this purpose, the pre-amplifiers and their corresponding supply apparatus for anode voltage and heating current for the four microphones in "Salle 12/13" are set up in the room itself. These are the only low-frequency amplifiers which are not situated in the central amplifier station. The principle of central technical control was retained, however, by arranging to have these amplifiers switched on from the control room by means of press buttons and corresponding automatic switches. For the sake of necessary reliability of working a group of four additional reserve amplifiers were introduced to replace a group which might be out of working order and they can be brought into action by means of a press button in the control room.

Since the switching on and off of the microphones must take place at a spot where it is possible to follow the proceedings of the meeting, a so-called poste de régie (*fig. 3*) is set up in each room in which are the potentiometers indicated by *R* in the diagram (fig. 1). These potentiometers serve solely to make the switching on and off of the microphones inaudible, and volume regulation and mixing do not take place at the poste de régie. Moreover there is a telephone as well as switches and lamps for signaling purposes at the poste de régie. These will be mentioned later on in this article.

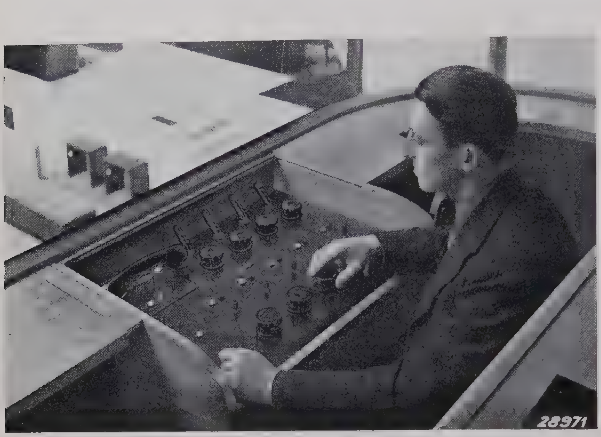

Fig. 3. Poste de régie in the "Salle des Assemblées". At the front of the control table may be seen the knobs for regulating the potentiometers *R*, and at the upper right-hand side the four switches for regulating the sound intensity of the loud speakers. Above these are the neon indicators which indicate the sound intensity at different spots in the hall (see the last section: signaling).

The pre-amplified, low-frequency voltage is conducted to mixing panels in the control room, which panels form part of the central operation and control table which may be seen in *fig. 4* at the right.

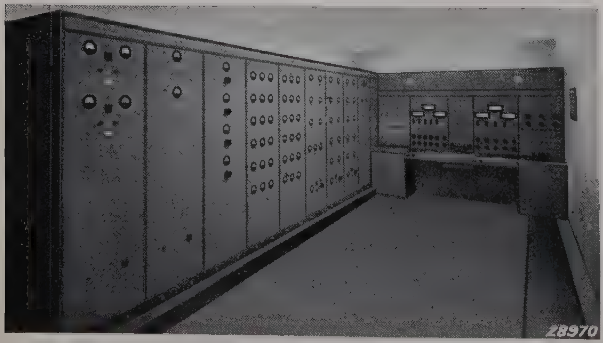

Fig. 4. View of the central amplifier station. In the background may be seen the control table on which the two mixing panels with their programme meters may clearly be distinguished.

There are two of these mixing panels, one with 4 and one with 5 channels (in fig. 1 only 2 channels of each mixing panel are drawn). In each channel there is a filter *F* and a potentiometer *P* with which respectively the low tones and the intensity of each microphone are regulated. For the sake of simple and rapid operation a neon indicator *N* is added for every channel. This is supplied by a special amplifier *V* and indicates whether or not there is low-frequency voltage on the line. In this way the time-consuming switching over of the head phones by the operator is avoided.

The modulation thus mixed is conducted from each mixing panel *via* the main volume regulator *H* and the intermediate amplifier *B* which raises the low-frequency voltage to the level of the line, to the main distribution lines, *I* and *II* respectively. To these main distribution lines all the components necessary for the realization of the objects mentioned in the introduction can be connected as desired. This is done in the case of those lines on which line level is required with the interposition of a separation amplifier *C*, in each line. These are the international telephone lines, the lines to the League of Nations Studio (Radio S. d. N.), to the cinema cabins, to the reporting cabins, to the apparatus for sound recording and the internal distribution lines. In this way the reliability of working is high, since the outgoing lines cannot react upon each other, and therefore in the case of disturbances in one of the lines, the others may remain in use with no difficulty. Moreover with the amplifiers C_1 extra line losses may be compensated for. The power amplifiers C_2 which supply the power loud speakers are connected directly with the main distribution lines without intermediate connection of amplifiers C_1.

Furthermore so-called monitor amplifiers C_3 are introduced, which make it possible to check the quality of the reproduction in the control room. For accurate control of the modulation, a set of so-called programme meters *PM* (fig. 1) is introduced on the control table for every pair of distribution lines. Each set of meters consists of three measuring instruments which indicate respectively the average voltage, the minima and the maxima, which occur on lines *I* and *II* during the transmission.

The lines to the reporters' cabins (7 in the "Salle des Assemblées" and 2 in "Salle 12/13") end in the respective cabins on mixing panels (see *M* in fig. 1). The reporters listen with head phones *K* to what is said in the hall, and they speak into a ribbon microphone (see *fig. 5* interior of reporters' cabin). The modulation given by this microphone is first amplified by a microphone pre-amplifier A, after which, *via* a filter F in the mixing panel, it can be regulated by the volume regulator P, and at the same time mixed with the modulation coming from the hall. In the case of "Salle 12/13" these pre-amplifiers are placed in the cabin itself, because of the great distance between microphone and control room, while for the "Salle des Assemblées" they are housed in the central amplifier station.

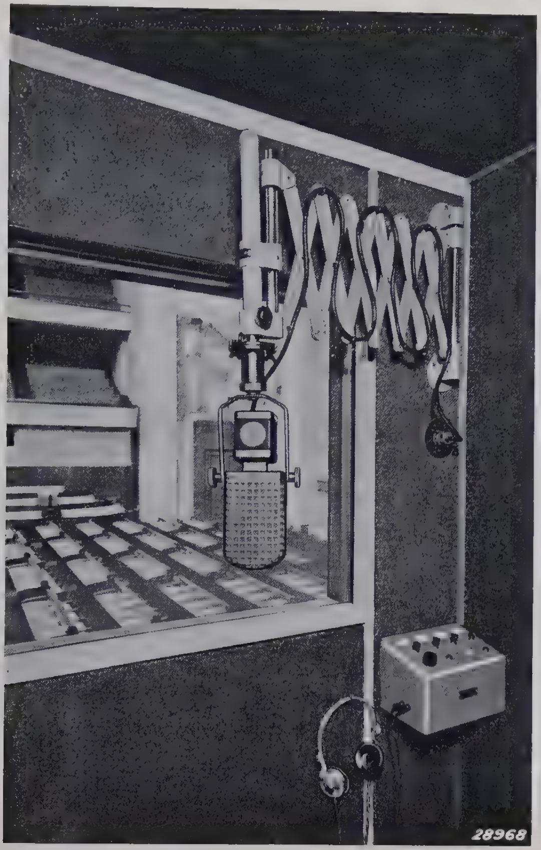

Fig. 5. Cabin for radio reporting. The reporter can follow the proceedings of the meeting through the window. The microphone is so connected that it can be moved in all directions inside the cabin.

In the cabins for taking cinema films (7 in the "Salle des Assemblées", see *fig. 6*, and 2 in "Salle 12/13"), the lines over which the modulation is conducted end at connection cabinets T (*cf.* fig. 1). Each cabinet contains a set of contact terminals upon which the cinema operator can tap off the modulation in order to record it on the film. In order to make the adaptation as suitable as possible for the most commonly used recording apparatus, a constant attenuation of 20 dB is introduced into each cabinet, while an adjustable attenuation of 30 dB at the most can still be added with a potentiometer. The cinema operator therefore may avail himself of an adjustable level which lies 20 to 50 dB below the line level, which is adequate for all cases which may occur. The same cabinets are also used for the connections with other apparatus for sound recording.

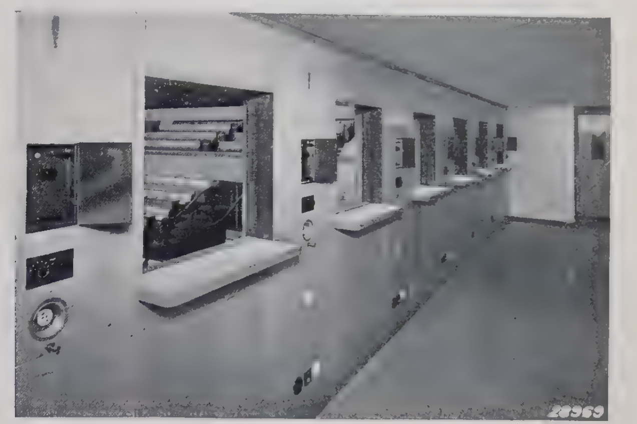

Fig. 6. View of the gallery for taking cinema films in the "Salle des Assemblées". The seven connection cabinets (T in fig. 1) for the recording of sound film may be seen on the wall.

The internal lines for sound distribution which, as we have seen above, are also supplied *via* amplifiers C_1, include thirty contact points throughout the building, where line voltage is therefore also available. To these points, which are of the usual type with plug-in contacts, amplifier units with built-in loud speakers are connected.

In the case of the power amplifiers C_2 which supply the loud speakers for the improvement of the acoustics and several other loud speakers which are placed in neighbouring halls and rooms, several special measures have been taken to regulate the frequency characteristic. For the improvement of the acoustics it is necessary to adapt the reproduction accurately to the acoustic characteristics of the hall in question, in order to obtain the greatest intelligibility and the best quality. Therefore for each hall special permanently adjusted filters F_1 were designed, and those amplifiers C_2 which serve to improve the acoustics are then automatically connected to these filters when they are connected to the outgoing line to the corresponding loud speakers in the hall. When they have to feed other power loud speakers a filter F_2 is automatically put in series, with which filter the frequency characteristic can be regulated as desired. In this way the principle was retained which holds for all amplifiers C_1 and C_2, namely that in each group they are all mutually entirely equivalent for the various purposes.

Amplifier levels

In such a large amplifier system with which the energies generated by a number of different voltage sources must be amplified, regulated and then distributed over a number of different reproducing apparatus, it is better not to have the total amplification between source of voltage and reproducing apparatus take place in one step. Care must be taken in the amplification that the energies are amplified in the first instance to such a degree that they may later be regulated and mixed without danger of introducing disturbances. Then the energies thus collected into only a few groups (line programmes) are amplified to a level suitable for the reproduction apparatus. By constructing the installation in this way it can be built up of the necessary number of similar, and therefore interchangeable, parts quite independent of the nature of the sources of voltage and the apparatus for reproduction.

We shall now examine how this principle is applied in the amplifier installation of the League of Nations Palace. As supply level for the reproduction apparatus has been chosen the so-called line level which is present on the main distribution lines *I* and *II* (see fig. 1), and which is so chosen that the average effective value of the low-frequency voltage corresponds with an energy of 6 mW. The height of the other levels occurring in the installation will be expressed with respect to the thus defined line level.

In determining the various amplifier stages we begin with the ribbon microphones used, which at a sound pressure of 1 dyne/sq cm give an energy which is $10^{-7,4}$ times the energy of 6 mW of the line level. In other words: this ribbon microphone has a sensitivity of — 74 dB with respect to the line level for a sound pressure of 1 dyne/sq cm. Most intensity maxima in normal speech, 100 cm away from the microphone, give a sound pressure of about 1 dyne/sq cm, while the average intensity of the sound is about 15 dB lower than this, and in several seldom occurring short maxima an intensity about 5 db higher is reached. Practical measurements carried out in the Philips Laboratory gave the above results, which agree very well with the data published by Fletcher [2]).

According to this author the maximum energy of the spoken word is about 1 mW. We may compare this figure with our measurements, and, starting with the sound pressure p in dynes/sq cm, we can calculate the power W of the source of sound.
W occurs in the formula:

$$W = \frac{4\pi r^2 p^2}{\varrho c}\ \text{erg/sec} = \frac{4\pi}{\varrho c}\, r^2\, p^2\, 10^{-7}\ \text{watt.}$$

where ϱ is the density of air, c the speed of propagation of sound, and r the distance from the microphone to the speaker. At a distance $r = 100$ cm from the speaker the sound pressure is 1.8 dyne/sq cm for the maxima of the spoken word. This is 5 dB higher than the average sound pressure of the spoken word (1 dyne/sq cm).
If therefore $r = 100$ cm, $\varrho = 1.8$ dyne/sq cm and $\varrho c = 42$, we find:

$$W = \frac{4\pi}{42}\, 100^2 \cdot 1.8^2 \cdot 10^{-7} = 10^{-3}\ \text{W} = 1\ \text{mW},$$

which agrees exactly with Fletcher's result.

In the case of speech in a hall the situation is somewhat different. In order to collect experimental data on this subject, intensity measurements were carried out in 1937 with a temporary amplifier installation with different speakers in the "Salle des Assemblées". The average intensity was in most cases found to be 5 to 15 dB higher than in a personal conversation, and in one case even 20 dB higher. This also agrees perfectly with the observations of Fletcher, who states that the sound intensity of loud shouting lies 20 dB above that of an ordinary conversation (*i.e.* it is a hundred times as great), and that certain persons, even in a personal conversation, reach an intensity of as much as 9 dB above the average. With a minimum distance of 70 cm to the microphone, therefore the highest maximum which occurs in the intensity lies about 23 dB higher than the sound intensity of an ordinary conversation with a distance of 1 m between the speakers.

Let us now consider the case of a soft speaker, whose intensity falls in the course of his speech to $^1/_5$ of the normal intensity, and who moreover stands at a distance of 2 m from the microphone. The level which he produces in the amplifier has only $^1/_{16}$ of the normal intensity and thus lies 12 dB lower.

With respect to the line level of 6 mW, the commonly occurring maxima therefore lie at
— 74 + 23 = — 51 dB for the loudest speaker,
— 74 — 12 = — 86 dB for the softest speaker.

As was mentioned previously, in normal speech the average intensity lies about 15 dB lower than the commonly occurring maxima, therefore for the case of the soft speaker considered this becomes a level of 6 mW.

The average sound level of the soft speaker and the maxima of a very loud speaker thus lie about 50 dB apart, and it is required of the amplifier system that it shall deal satisfactorily with these two sound energies which differ by a factor of 100 000. The maxima in the softest speech must be brought to the line level of 6mW by the amplifier system. A maximum amplification of 86 dB is thus required. A total weakening of about 14 dB occurs in the filters and sound mixers, so that the amplifiers A and B together must amplify about 100 dB. 50 dB has been chosen as the amount for each amplifier stage.

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[2]) Fletcher, Bell system techn. J. **10**, 349, 1931.

Behind the mixing panel therefore the intensity at the peaks would vary from — 50 to — 15 dB, and behind amplifier B from 0 to + 35 dB, if no volume regulation took place. It is true that the amplifier B has only 1 per cent distortion at + 10 dB, above this, however, the distortion increases quite rapidly (*cf.* fig. 8). It therefore seems desirable, and it has actually been shown by audition experiments, that care must be taken that the maximum peaks occurring do not exceed 10 dB. From this it follows that the mixing potentiometers and the main volume regulator must be able to give an attenuation of at least 25 dB.

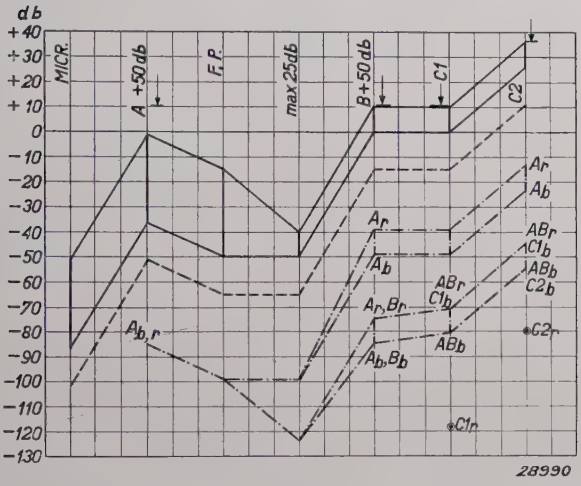

Fig. 7. Scheme of energy levels. The broken line gives the variation of the average energy level for the softest speaker; the continuous line directly above it represents the variation of intensity of a normal speaker; the upper continuous line represents the variation for the loudest speaker. The lines thus — . — . — . — represent the interference levels, and following the potentiometer P this is drawn for the two extreme positions of volume regulation.

A_r	noise level amplifier A,	A_b	hum level amplifier A,
B_r	noise level amplifier B,	B_b	hum level amplifier B,
C_{1r}	noise level amplifier C_1,	C_{1b}	hum level amplifier C_1,
C_{2r}	noise level amplifier C_2,	C_{2b}	hum level amplifier C_2,
F	filter,	P	mixing potentiometrs.

The amplifiers A, B, C_1 and C_2 have a distortion of less than 1% at the levels indicated by an arrow.

Fig. 7 shows how the energy levels vary in the different stages of the whole amplifier system, while the position of hum and noise levels is also indicated. For amplifiers A these latter levels are both — 85 dB, they are reduced to — 99 dB by the filters F. Following potentiometer P in fig. 7 the variation of the hum and noise levels are drawn for the *two extreme limits* of volume regulation. Depending upon the position of the potentiometers the hum and noise levels then have a value which lies between — 99 and — 124 dB. The noise level of amplifier B lies at — 75 dB, this is 10 dB higher than that of A. This rise of 10 dB is due to the fact that the frequency characteristic of amplifier B from 2 000 c/s increases to + 14 dB at 10 000 c/s, which is necessary for compensating a corresponding fall in the frequency characteristic of the ribbon microphone.

The hum level of amplifier B is — 85 dB like that of A; because of this the hum and noise levels behind amplifier B differ by 10 dB as may be seen in fig. 7. In the minimum position of the volume regulators the noise contributions as well as the hum contributions of A and B are the same following amplifiers B, so that the total interference level is about doubled, which means an increase of these levels by 3 dB to AB_r and AB_b respectively (*cf.* fig. 7). In the maximum position of the volume regulators, on the other hand, the hum and noise contributions of amplifiers B are small with respect to those of A following amplifiers B, so that the hum and noise levels A_r and A_b in that case increase scarcely at all.

The hum and noise levels behind amplifiers C_1 and C_2 are calculated in the same way. It may be noted that with amplifiers C_1 and C_2 the hum is stronger than the noise, in contrast to amplifiers A and B. This must be ascribed to the fact that the heating elements of amplifiers C_1 and C_2 are supplied with alternating current and those of A and B with direct current. In the most unfavourable case with regard to the occurrence of disturbance, namely when in the case of a soft speaker the potentiometers are wide open, the hum levels of amplifiers C_1 and C_2 still, however, lie so low that the final hum level behind these amplifiers, which is chiefly due to amplifier A, is practically not increased.

Finally it may be seen that the average intensity of speech of the softest speaker at the end of the installation lies at + 24 dB with respect to the maximum noise level which is chiefly due to amplifiers A. As soon as the speech into the microphone becomes louder, the ratio between noise and sound intensity becomes more favourable.

We shall now deal with the construction of the different kinds of amplifiers which were used in this installation.

These amplifiers may be divided into two groups:

1) The pre-amplifiers: A and B.
2) The final amplifiers, to which belong:
   the separation amplifiers C_1,
   the power amplifiers C_2 and
   the monitor amplifiers C_3.

The pre-amplifiers A and B

Of very great importance is the quality of the first amplifier *A*, whose noise level must be as low as possible, while all variations of intensity must be reproduced without distortion. In *fig. 8* it may be seen that amplifier *A* satisfies these conditions. With an output of + 10 dB above 6 mW a distortion of only 1 per cent occurs, while it may be expected that the intensity at the peaks will not rise higher than to about 6 mW. The noise level of — 85 dB with respect to 6 mW at the output lies only slightly higher than the noise level which may be expected theoretically due to the presence of the resistance in the grid circuit of the first amplifier valve.

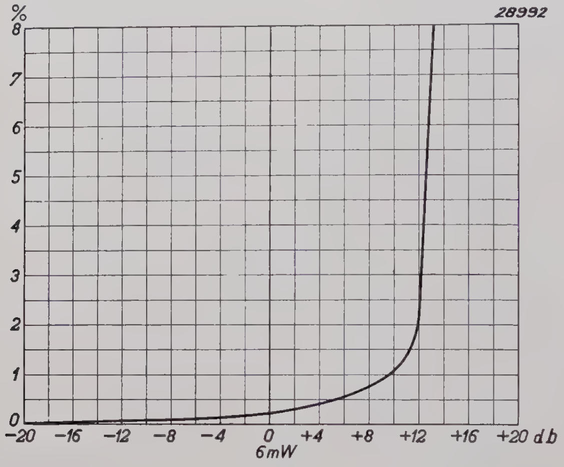

Fig. 8. Distortion characteristic of the amplifiers *A* and *B*.

Amplifiers *A* and *B* consist of two amplifier stages with inverse feed-back. The inverse feed-back is introduced in order to keep the distortion very low over a wide range and moreover in amplifier *B* in order to be able to change the characteristic of the amplifier easily in such a way that the decrease in the sensitivity of the microphone for high tones is thereby compensated.

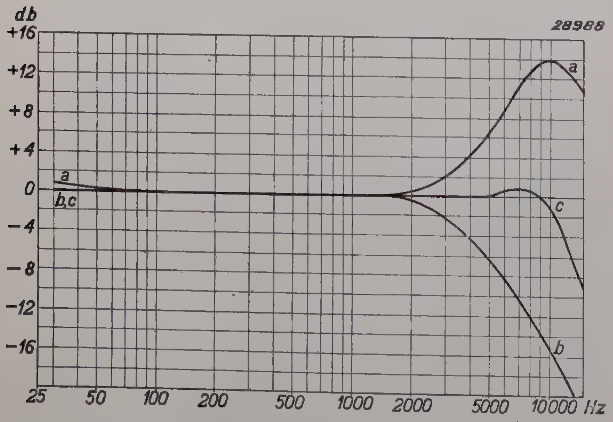

Fig. 9. Frequency characteristic of amplifier*B* combined with the frequency characteristic of the ribbon microphone.
a = frequency characteristic of amplifier *B*,
b = ,, ,, ,, ribbon microphone,
c = ,, ,, ,, both together.

In *fig. 9* line *a* gives the frequency characteristic of amplifier *B*. Line *b* is the characteristic of the microphone. The combination of *a* and *b* gives line *c*, which thus represents the total frequency characteristic of the microphone with the amplifiers *A* and *B*, since the frequency characteristic of amplifier *A* is straight.

The amplifiers C_2, C_1 and C_3

The power amplifier C_2 consists of two resistance-coupled push-pull stages with inverse feed-back, and the frequency characteristic is straight from 30 to 10 000 c/s. The non-linear distortion is also very slight (see *fig. 10*). Up to the maximum output power of 25 W the distortion for all frequencies from 65 to 4 000 c/s is less than 1.3 per cent. These amplifiers like *A* and *B* are constructed in panel form (*fig. 11*).

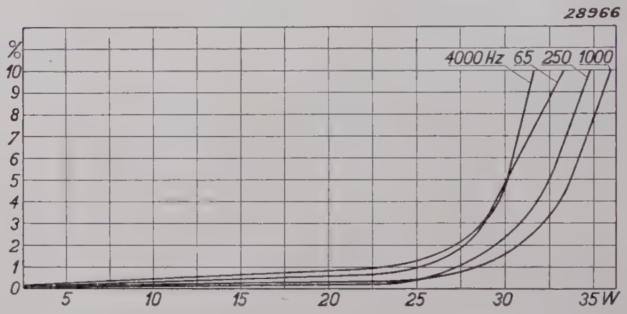

Fig. 10. Distortion characteristic of amplifier C_2 at different frequencies.

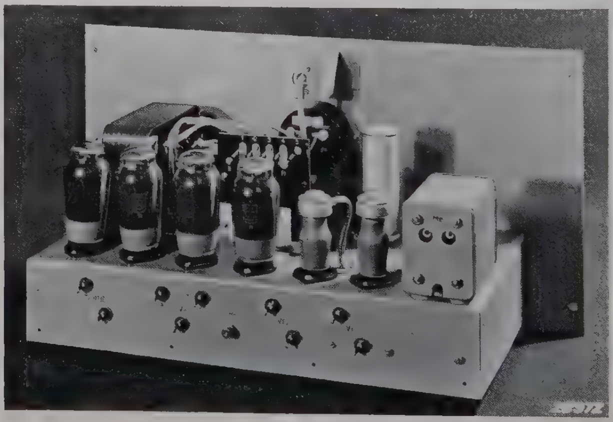

Fig. 11. Amplifier C_2.

The separation amplifier C_1 consists of a simple one-stage amplifier with volume regulation, and can give on the line a level of 10 dB above 6 mW with less than 1 per cent distortion. Three of these are mounted on one panel. The monitor amplifier C_3 is of the same type as the power amplifier C_2 but of smaller energy.

The anode voltage apparatus of all amplifiers except the monitor amplifier C_3 are kept entirely separate from the amplifier part, in order to prevent the power transformers and smoothing chokes from causing hum in the amplifiers.

Signaling

It will be clear that considering the extensiveness of the installation a practical signaling system is indispensable in order to avoid incorrect switching manipulations at the various operating spots which are separated from each other. The places where switching processes are carried out by various persons, except in the central amplifier station, are: postes de régie, the reporters' cabins and the studio of the League of Nations transmitters.

The simplified diagram of the signaling system (*fig. 12*) makes clear the guiding principle according to which this system is arranged. Only two signals are used, one white (L_1) and one red (L_2). The white signal light is the preparatory signal, the red one indicates that all the manipulations which are necessary for carrying out the transmission are complete. Incorrect switching manipulations are furthermore betrayed by intermittent red light (L_3).

When for example a microphone must be set working, the operator at the poste de régie must throw the key k. It may be seen in fig. 12 that then the white lamps in the control room and at the poste de régie are lighted. This is carried out per channel, so that it can immediately be ascertained in the control room which microphones are to be used. At the same time this is the signal for the personnel in the control room to begin with the preparations for the transmission.

The desired connections to the outgoing lines are made by means of the flexible conductors with jacks and sockets on the central control table. All such conductors which are connected with the outputs of the amplifiers C_1 have a third strand (+), while the socket of the outgoing lines for which signaling is necessary are provided with auxiliary contacts over which the auxiliary signal currents are supplied. If for example we consider a line to the studio, we see in fig. 12 that when the jack of a cord is stuck in the socket a white lamp is lighted in the studios, because the relay C attracts its armature and the contacts c are closed. This lamp indicates the room from which the transmission is taking place. When the personnel in the studio, having noted the white signal, has connected the line with the transmitter (whereby a contact V_L

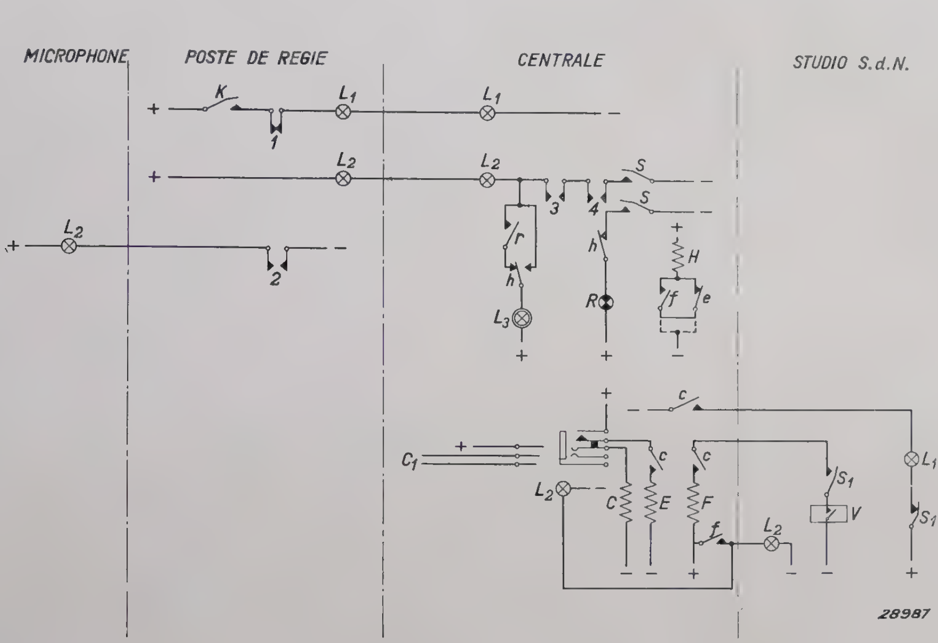

Fig. 12. Simplified diagram of the signaling system in which all relay contacts are shown in the currentless state.
L_1 white lamps, L_2 red lamps, L_3 red control lamp,
K key at the poste de régie, S key on the mixing panel in the control room,
S key on the connection panel in the studio,
1 and *2* are contacts on potentiometers of the poste de régie,
3 and *4* are contacts on potentiometers of the mixing panel in the control room,
V contact on connection plug in the studio, R relay interruptor with accompanying contact,
C, E, F and H are relays with accompanying contacts c, e, f and h.

is closed) and has opened the volume regulator, the key S_1 is thrown and the relay F is thereby brought into action, so that the contacts f are closed and the red lamp L_2 near the socket in the control room begins to burn. It may be seen clearly that this signal cannot be given before all the manipulations just mentioned (closing of V and S_1) have been completed in the studio. When in the control room the state of the outgoing lines has been ascertained, the channel potentiometers are opened on the mixing panel. These potentiometers possess contacts (*3* and *4* in fig. 12) which are mechanically coupled with the axle, and which are closed as soon as the potentiometer is turned away from the zero position. If the key S is then thrown, the red lamps L_2 corresponding to channels in use at the poste de régie (and those in parallel on the mixing panel) begin to burn. The operator of the poste de régie now knows that they are ready in the control room for dealing with the transmission, and he may therefore set the microphones in action. This takes place, as was mentioned above, by the wide open setting of the microphone potentiometers. These potentiometers also have auxiliary contacts (*1* and *2* in fig. 12) coupled with the axle, which, however, only come into action when the potentiometer is turned to its utmost position. At that moment *1* is opened and *2* is closed. The white lamps L_1 are hereby extinguished, so that in the control room it may be ascertained immediately which microphone is switched on, while at the same time a red lamp L_2 is lighted near the microphone, so that the speaker can now finally see that his microphone is working.

It may also be seen from the figure how it is known in the control room that for instance a mistake has been made in the studio. In such a case the red lamp is not lighted at the corresponding socket, because the relay F has not worked and the contacts f are therefore not closed. If nevertheless the key S is reversed, an intermittent light from the red control lamp L_3 serves to remind those in the control room that there is a disturbance on one of the lines. In these cases the relay H falls out, since the relay E has functioned and the contact e for non-working is opened, while the contact f in parallel with it is also opened. A contact h for non-working switches in a relay interruptor R by which the contact r regularly interrupts the current circuit of the control lamp L_3. A similar connection is used for the lines to the reporter's mixing cabins.

A special signaling system is introduced in the "Salle des Assemblées" for the regulation of the sound intensity of the loud speakers for improving the acoustics. The sound intensity of each of the loudspeakers set up in the hall can be regulated separately with switches which are placed at the poste de régie (*cf.* fig. 3). Since the desired sound intensity is dependent on the number of persons seated in the hall, and since this sound intensity naturally cannot be judged for the whole hall at the poste de régie, control points are equipped at four places in the huge hall from which the operator at the poste de régie can be informed whether the sound intensity must be made greater or smaller. At the poste de régie, above every intensity regulator, a neon indicator lamp has been introduced. (In fig. 3 these neon indicators may be seen in a poste de régie of the "Salle des Assemblées" in the backward slanting metal holders which are placed above the upper row of knobs). At each control point in the room a switch button has been fastened to the wall, which has three positions. With this button resistances are put in series with the neon tube, in such a way that the length of the light streak corresponding with the three positions of the switch, can be made short, medium and long, to indicate that the sound in the room is too soft, satisfactory or too loud respectively.

THE PRODUCTION AND USE OF NEUTRONS

by F. A. HEYN.

539.185

The uncharged particles of matter with almost the same mass as a hydrogen atom, discovered by Chadwick in 1932 and called neutrons, are of great importance, not only for science, but also for various practical applications, for example in chemical, biological and even medical problems. For the production of neutrons so-called nuclear reactions may be used, in which certain elements are bombarded with α-particles from radium, for instance, or with deutons, which are ions of heavy hydrogen generated in a canal ray tube and accelerated by means of high voltages. The apparatus necessary for obtaining the fast deutons is described in detail in this article. With such a neutron generator for 600 kV, $6 \cdot 10^9$ neutrons per second are obtained; upon the use of α-particles from a natural source instead of deutons, 300 g. of radium would be necessary for the same yield of neutrons.

It is not so long ago (1932) that Chadwick discovered the elementary particles of matter which he called "neutrons", and which have been added as new components of matter to our picture of the universe along with the already known electrons and protons. In the few years which have elapsed since their discovery, numerous experiments have been carried out which have enlarged our knowledge of the properties of these particles. At the same time the technique of producing neutrons has made great progress, especially since it soon appeared that neutrons could be put to practical uses.

The discovery of the neutron was considered to be of such great importance that Chadwick was awarded the Nobel Prize. Actually he was not the first to observe the existence of neutrons: German physicists had already noticed that when beryllium is bombarded with α-particles (helium nuclei emitted by radio-active substances), it sends out a very penetrating radiation which can be shown by the ionization which it causes under certain circumstances. They believed themselves to be concerned with γ-rays (extremely hard X-rays).

This radiation was also investigated by others, but Chadwick was the first to be able to prove that there was no question of γ-rays here, but that the beryllium, when bombarded with α-particles, sends out uncharged particles of matter with a mass about equal to that of the proton, *i.e.* the nucleus of the hydrogen atom. These neutral particles were called neutrons. It soon appeared that they play a very important rôle in the structure of atomic nuclei [1]).

Principles of the production of neutrons

According to present conceptions atomic nuclei are composed of neutrons and protons. If we wish to obtain free neutrons, we must get them out of the atomic nuclei. This can be done by bombarding the nuclei with fast particles, for instance with the already mentioned α-particles. nuclear reactions then occur, in which, in some cases, neutrons are freed from the nucleus. For example in the experiment which led Chadwick to make his discovery, the nuclear reaction proceeded as follows:

$$\mathrm{Be} + \alpha \rightarrow \mathrm{C} + \mathrm{n}, \quad \cdots\cdots \quad (1)$$

which means in so many words that a beryllium nucleus, struck by an α-particle (α), is transformed into a carbon nucleus [2]) with the emission of one neutron (n). In practice this reaction is brought about simply by mixing beryllium powder with a substance which emits α-particles, such as radium or radium emanation. The mixture then emits neutrons in all directions.

The yield of reaction (1) is not high. If we bombard beryllium with the α-particles produced by 1 mg. of radium, *i.e.* $1.5 \cdot 10^8$ α-particles per second, we obtain about $2 \cdot 10^4$ neutrons per second. Thus only one in about seven thousand α-particles produces a neutron. With other substances bombarded with α-particles we find a still lower yield. If for example 100 mg. of radium is available it is possible in this way to produce $2 \cdot 10^6$ neutrons per second.

This quantity of neutrons is usually insufficient for the applications to be mentioned later. More radium (*i.e.* more α-particles per sec.) would be necessary. Aside from the very great expense, however, the world's supply of purified radium is limited, so that the investigator will not in general have a larger quantity than the above-mentioned (100 mg) at his command.

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[1]) *Cf.* for instance: W. de Groot, Nuclear Physica, Philips techn. Rev. **2**, 97, 1937.

[2]) The reactions are here given roughly. If the atomic weights are taken into account, it will be seen that the newly formed atoms are usually isotopes which rarely occur in nature.

Fortunately other nuclear reactions are now known in which neutrons are freed. In the first place there are the reactions in which "deutons", nuclei of heavy hydrogen (the isotope with atomic weight 2 of normal hydrogen, indicated by D as abbreviation for "deuterium"; d is the abbreviation for deuton), are used as projectiles. While the fast α-particles are supplied by nature in the form of radium rays, the fast deutons necessary for bombardement must be produced artificially in the following way.

Ions are produced in a discharge tube filled with heavy hydrogen; these ions, which are the desired deutons, are then accelerated by means of high voltages in some way or other. This technique is much more complicated than that used in reaction (1), but the results are also much better. While the yield of the reactions with deutons is indeed lower than of those with α-particles, the number of projectiles can be made much larger, so that many more neutrons are finally obtained. If for example lithium is bombarded with deutons with the following reaction as a result:

$$\mathrm{Li} + \mathrm{d} \rightarrow 2\,\mathrm{He} + \mathrm{n}, \quad \cdots\cdots \quad (2)$$

the yield (with an accelerating voltage of 600 kV) amounts to $3 \cdot 10^{-6}$, *i.e.* only one in $3 \cdot 10^{5}$ deutons gives a neutron. If, however, our apparatus produces a number of deutons corresponding with a current of 1 mA, *i.e.* $6.3 \cdot 10^{15}$ deutons per second we obtain more than $2 \cdot 10^{10}$ neutrons per second, thus many more than with the α-particles from 100 mg of radium. The voltages and current hereby assumed may easily be realized in practice.

Other possible nuclear reactions are the following:

$$\mathrm{D} + \mathrm{d} \rightarrow \mathrm{He} + \mathrm{n}, \quad \cdots\cdots\cdots \quad (3)$$

and

$$\mathrm{Be} + \mathrm{d} \rightarrow \mathrm{B} + \mathrm{n}, \quad \cdots\cdots\cdots \quad (4)$$

in which heavy hydrogen itself and beryllium, respectively, are bombarded with deutons. It is not only possible to produce considerable quantities of neutrons per second with these reactions, but the neutrons here produced in general also possess a higher energy than those produced in reaction (1). This is very important in many applications.

The bombardement with fast deutons is therefore used in the Philips Laboratory for the production of neutrons and the previously described high voltage generators 3) give excellent results in this process. We shall describe here several of the neutron generators developed.

Neutron generator for 300 kV

The chief element of the neutron generator, namely the tube in which the deutons are produced and accelerated, is in principle similar to a canal ray tube. *Fig. 1* gives a diagram of such a tube. The tube is filled with a gas (in our case heavy hydrogen) at low pressure. Between the cathode K and the anode A a discharge takes place, and ions are formed which move toward the cathode. Part of these ions pass through a hole in the cathode K in the right hand part of the tube, and are accelerated by the voltage V_v between K and B. The accelerated ions pass into the cylinder B. If neutrons are to be produced, the ions are allowed to fall on a target T of suitable material at the end of B. For the convenience of the investigator the tube is earthed at this end. The discharge in the space between K and A, which we shall call the ion source, can be maintained by thermionic emission from K, or it may be an ordinary glow discharge for which a sufficiently high voltage V_b between A and K is necessary and not too low a gas pressure 4). This last method has been used in our case.

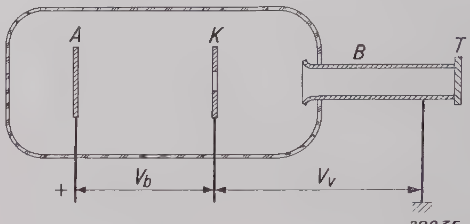

Fig. 1. Diagram of a canal ray tube. By a discharge between K and A ions are produced which pass through a canal in the cathode K and are accelerated by a voltage V_v between K and B. The ions may be allowed to strike a target at T.

In order to obtain a satisfactory yield of neutrons with such a canal ray tube, a very high accelerating voltage V_v is necessary, as well as a high current of the ion beam. With these objects in view the tube shown in *fig. 2* was constructed 5). A value of 300 kV was chosen for the accelerating voltage. A certain insulation length of the tube is necessary in order to avoid breakdown through the air along the outside wall of the tube. On the other hand, however, breakdown and the occurrence of a discharge in the accelerating tube must also be avoided, since that would mean a breaking down of the high

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3) See for example: A. Bouwers and A. Kuntke, Z. techn. Phys. **18**, 209, 1937. *cf.* also Philips techn. Rev. **1**, 6; 1936 and **2**, 161, 1937.

4) At least if no special measures are taken, such as the use of a magnetic field. F. M. Penning and J. H. A. Moubis: Physica **4**, 1190, 1937; *cf.* also Ned. T. Natuurk. **5**, 102, 1938.

5) The tube is a modified type of that first proposed by Oliphant and Rutherford.

voltage. This may be done by making the gas pressure very low in the space between K and B, and the distance very short between K and B. A low gas pressure corresponds to a long free path λ of the electrons which are freed by collisions of ions with the electrode B. These electrons, when their path from B to K is much shorter than λ, will cause no appreciable ionization, *i.e.* no breakdown will occur. The two requirements: great insulation length in air, small separation in the vacuum, led to the construction which is shown in fig. 2. The source of ions S is placed in the accelerating tube G.

Source of ions

It is important for the discharge to take place at the source of ions in such a way that as many ions as possible pass through the canal k, *i.e.* the discharge must be concentrated in the neighbourhood of k. With the shape indicated of the discharge space S such a focussing action is automatically obtained. The discharge follows approximately the directions of the dotted lines between the partition L soldered on to the anode A and the neighbourhood of the canal in electrode K. In order to prevent the occurrence of a discharge at other spots between A and K, as was explained for the accelerating space W, the distance between the electrode cylinders is made so small (see fig. 2) that, with the gas pressure used, it is still small compared with the free path of the electrons. The insulation between the electrodes A and K is formed by the glass cylinder J, which is connected by airtight chrome-iron glass joints with the flanges C and E.

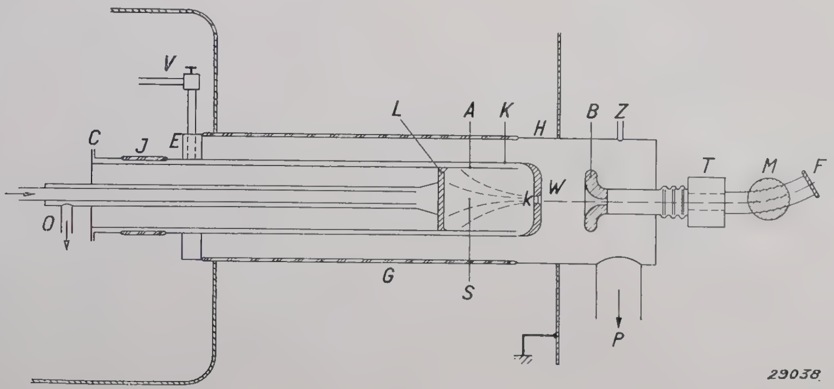

Fig. 2. Cross section of the tube constructed. S discharge space of the source of ions. A and K electrodes. L cooled partition: at 0 the cooling water or oil enters and leaves. J glass cylinder for insulation fused to the flanges C and E of the electrodes A and K. V needle valve. G accelerating tube. The ions pass through the canal k and are accelerated in the space W between the electrodes K and B. H earthed metal cylinder. The pump is connected at P, a manometer at Z. T stopcock. M magnetic field. A Faraday cage is connected at F, or, after removal of the magnetic field, a target is placed at the end of the tube.

At a voltage of 50 kV and a current of 40 mA a power of 2 kW is transformed at the source of ions. The heat hereby developed makes good cooling necessary. The electrode K dissipates its heat by radiation; the partition L in the electrode A is cooled with running water which enters and leaves at 0. Since A is at high voltage, a closed cooling water circuit with an insulated pump is necessary. If it is desired to avoid the insulated pump installation, oil may be used for cooling, and this is conducted to the apparatus through glass tubes (visible in the photograph fig. 7 at the extreme left).

The electrode K must be able to withstand a vigorous bombardement with ions, and is therefore made of aluminium which erodes relatively little and also possesses a good heat conductivity. The electrode A and the wall L are made of chromium-plated copper, since a copper surface easily leads to an arc discharge.

The canal k has a length of 5 mm and a diameter of 3 mm. The greater the diameter the greater the percentage of ions which can enter the accelerating tube. In determining the dimensions of the canal, however, the gas pressure must be taken into account. As already stated, the gas pressure must be very low in the accelerating tube (of the order of $5 \cdot 10^{-4}$ mm of mercury). The pressure at the ion source may however not be too low, since otherwise the voltage necessary to obtain a discharge would be too high. It is therefore necessary to maintain a certain difference in pressure between ion source and accelerating tube, which is done by rapid pumping *via* P. The pumping speed of the pump used (an oil-diffusion pump with a speed of 20 litres per second) therefore determines the permissible dimensions of the canal.

In order to replace the gas which is continually pumped away, fresh hydrogen is continually added through an opening in the flange *E*. The pressure in *S* can be regulated while the tube is under tension by means of a needle valve *V*, which is operated *via* an axle of insulating material. This regulation is very important, since the number of ions which enter the accelerating tube from the source depends strictly upon the pressure.

Acceleration of the ions

The acceleration of the ions takes place in the acceleration space *W* between *K* and *B* (length 5 cm) in tube *G*, which is 80 cm long and 20 cm wide, and may be made of glass or of artificial resin ("Philite"). With the latter material the chance of breakage or breakdown is much less, while it is very satisfactory as to vacuum and high voltage. The electrode *B* is also of chromium-plated copper, and has such a shape that the field strength at its surface is as low as possible, in order to avoid cold emission of electrons. The wide edge of *B* provides for a variation of the field between *K* and *B* such that the electrons, which are formed by the bombardment of ions in the neighbourhood of the opening in *B*, are unable to leave the acceleration space *W*. This point is important for the satisfactory functioning of the tube, since otherwise the freed electrons wandering about outside *W* can cover great distances and may also cause secondary emission. The high ionization caused by all this might finally cause breakdown. For the same reason, *i.e.* in order to prevent the stray electrons from doing any harm, the metal cylinder *H* extends slightly beyond the ends of the actual acceleration chamber *W*. The part of *K* around the exit of the canal is made concave in order to obtain a concentration of the ion beam.

After the acceleration the ion beam passes a stopcock *T*, a magnetic field *M*, and falls upon *F*. If the current of the ion beam is to be measured a Faraday cage is connected at *F* (it must be cooled with water). For the production of neutrons the magnetic field is first removed, and the already mentioned target is introduced, for example a plate of lithium which, upon bombardment with ions of heavy hydrogen, sends out neutrons in all directions (reaction (2)). The neutrons pass through the walls of the tube to the outside since they are practically unabsorbed. By means of the stopcock *T*, the main part of the tube is shut off when the target is to be changed.

The magnetic field *M* serves to determine the yield of active projectiles of the tube, *i.e.* to separate the ions of heavy hydrogen from the other ions present (from impurities in the gas), and also to separate the ions of the heavy hydrogen molecule (D_2^+) and the heavy hydrogen atom (D_1^+; in the reaction equations we have used d following ordinary usage).

These two kinds of ions are deflected by different amounts in the magnetic field because of their different masses. *Fig. 3* gives the part of the magnetic "spectrum" of the ion beam which is important for our purposes. The second and third maxima correspond to the atomic ions and the molecular ions respectively, while the first (D_{2-1}^+) may be ascribed to particles which are dissociated in the space between *B* and *M*, and which are therefore accelerated as molecular ions, but are then deflected as atomic ions. The second maximum is lower than the third, *i.e.* the number of atomic ions is smaller than the number of molecular ions, which was to be expected since at the ion source the formation of molecular ions (D_2^+) is the primary process in the production of deutons (D_1^+). The ions of the second maximum are the most effective in the production of neutrons, since they have the greatest velocity.

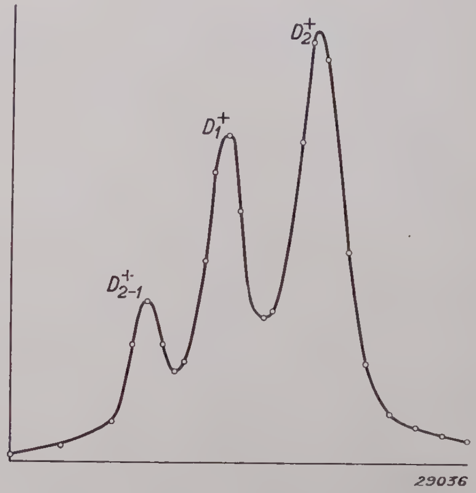

Fig. 3. Part of the magnetic "spectrum" of the ions in the ion beam. The deflection in the magnetic field is plotted horizontally, the ion intensity vertically. The ions D_1^+ (deutons d) of the middle maximum are chiefly effective in the production of neutrons, since they possess the greatest velocity.

The total current of the ion beam reached a maximum of 1.5 mA with this tube. The source voltage was 50 kV and the source current about 40 mA, while the acceleration voltage lay between 250 and 300 kV.

The accelerating voltage is supplied by a high tension generator of a type which has been described previously in this periodical [3]). The excitation of the source voltage of 50 kV is a problem by itself, since this voltage must be supplied to the electrodes A and K which are already at a potential of 300 kV with respect to earth. Use is usually made of a highly insulated transformer or of an insulated generator which is driven by a motor with an insulating belt or axle. In the Philips neutron generators, however, a circuit is used which corresponds in principle with the well-known cascade circuit of two stages. The right half of fig. 4 shows the scheme. The condenser of the first stage of the cascade circuit is replaced by two condensers C_1 and C_2 in series. This does not alter the principle, and C_3 will receive double the transformer voltage as in the ordinary cascade circuit; C_1 and C_2, however, are insulated for 300 kV, so that the appropriate electrodes of the tube can be connected at K and A. This solution has various advantages: it is very economical, the apparatus occupies little space, it causes no noise or vibrations and makes possible an easy regulation of the source voltage by regulation of the primary voltage of the transformer. In order to keep the ripple on the source voltage small, even at currents up to 40 mA, without C_1 and C_2 being made very large, a frequency of 500 c/s is used. For this a converter from 50 to 500 c/s is necessary, but this solution still remains more economical than the use of large condensers for C_1 and C_2.

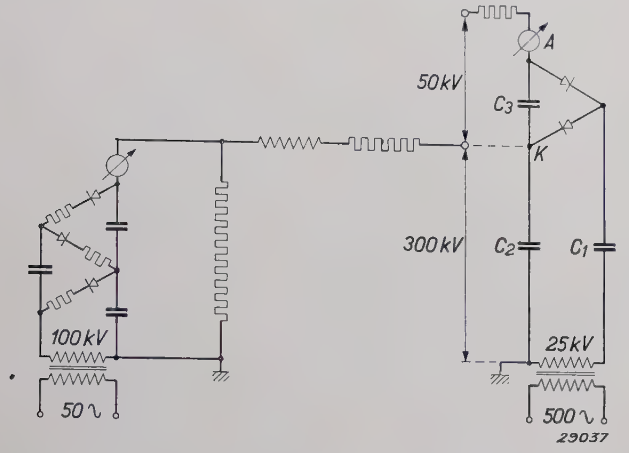

Fig. 4. Sources of high voltage for the neutron generator. In the left-hand part the accelerating voltage of 300 kV is generated with the well known cascade connection; in the right-hand part the source voltage of 50 kV which is supplied to the electrodes A and K, the latter of which is raised to a potential of 300 kV with respect to earth.

Fig. 5 is a photograph of a complete neutron generator constructed for the Laboratoire des Rayons X in Paris. The partition from which the sliding door is removed forms the separation between two rooms, at the left the workroom, at the right the high tension room. The tube passes through the partition, so that the neutrons are produced on the earthed target in the workroom. The pump installation is also placed in that room, and is mounted on the left-hand side of the partition, while the high voltage apparatus is also operated from there.

When the neutrons are produced according to reaction (2), the yield from this apparatus is $2 \cdot 10^8$ neutrons per second. In order to obtain the same quantity of neutrons with α-particles from radium, according to reaction (1) 10 g of radium would be necessary with a value of about £ 55,000.

Neutron generator for 600 kV

While the intensity of neutrons obtained with the apparatus for 300 kV is sufficient for many physical experiments, it is not adequate for biological and medical applications. An installation for 600 kV was therefore designed. For this purpose a second tube is connected with the earthed end of the tube in fig. 2, in which the ions are further accelerated by a negative voltage of 300 kV with respect to earth. In this way the target situated at the extremity of the second tube is under high tension. This is, however, no objection for most applications, while a construction with an earthed target, in which therefore a voltage of 600 kV with respect to earth had to be generated, would be many times as expensive. The arrangement is drawn schematically in *fig.* 6. The left-hand part is in the main similar to the 300 kV tube described. The two electrodes Q and R of the second accelerating tube, between which the ions are accelerated the second time, are again of chromium-plated copper. Special provisions are necessary for the concentration of the ion beam on the target. The shape and separation of Q and R have little effect on this, since in this region the heavy fast particles can only be slightly deflected by any irregularities in the variation of the field. Very important, however, is the separation and shape of the electrodes K and B of the first accelerating tube where the particles still have only low velocities. Since the beam never leaves the first accelerating tube exactly in the direction of the axis, the second tube is connected with the first by a flexible joint (a piece of tombak tubing) and suspended (at D) in such a way that it can be set in the direction of the beam, and all the ions can impinge on the target.

The current in the second tube is 0.5 mA at the most, so that at 600 kV an energy of 300 W is given off at the target which makes good cooling necessary. This is done by means of oil.

Due to erosion under the bombardement with ions a cavity is formed in the target after some time; impurities (decomposition products of vapours of grease) are also deposited upon it. By means of the second flexible connection N stopcock and target can be shifted so that the ion beam, which has a cross section area of several sq.mm, strikes the target at a different spot.

The yield of the apparatus for 600 kV is $6 \cdot 10^9$ neutrons per second, according to reaction (2). In order to obtain the same quantity of neutrons by reaction (1) with α-particles from radium, 300 g of radium would be needed!

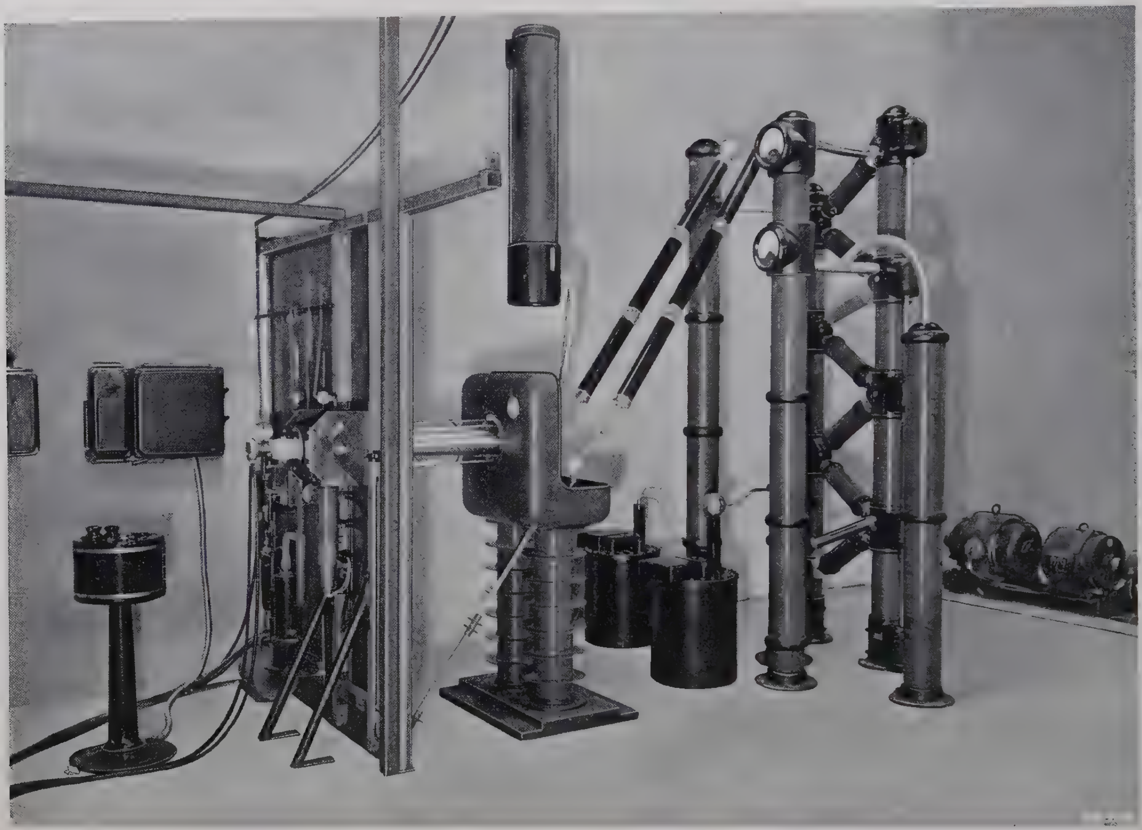

Fig. 5. Photograph of a complete neutron generator for 300 kV, constructed for the Laboratoire des Rayons X in Paris. In the high voltage chamber to the right of the partition (from which the sliding door has been removed) is the canal ray tube with a high voltage apparatus. At the extreme right stands the converter from 50 to 500 c/s. for the source voltage. Above the tube may be seen the insulated cooling pump. The extremity of the tube projects through the partition into the workroom on the left, where the neutrons are produced on an earthed target, and where all the control apparatus necessary for working are set up.

Fig. 7 is a photograph of the complete apparatus for 600 kV.

Several properties of neutrons

The use to which neutrons may be put is of course determined entirely by their unusual properties, several of which we shall mention here.

Since neutrons are neutral they cannot react electrically with the electrons and atomic nuclei of matter. Only by direct collision with atomic nuclei can neutrons lose energy and change their direction. It is because of this fact that their power of penetrating into matter is very great: those forces which have the greatest stopping power for electrons and ions are lacking here.

There are, however, several special substances which absorb neutrons strongly, chief among these are all hydrogen compounds, especially water and paraffins with a relatively high hydrogen content. If a neutron collides with a hydrogen nucleus, the collision is one between two almost equally heavy particles, and one particle, the neutron, can give off a large part of its energy to the other, the hydrogen nucleus. The neutron is thus strongly retarded. In addition, the hydrogen nucleus, like many other atomic nuclei, has the property of combining with slow neutrons. The result is a strong absorption. Of the other neutron absorbing materials we mention particularly cadmium, samarium, europium and gadolinium. These substances absorb neutrons, especially when the neutrons have first been retarded, by means of water for example. The uncharged neutrons penetrate particularly easily into the nuclei of these elements and are held permanently by the nuclei.

Another special property of neutrons, and for practical purposes perhaps the most important one, is that practically all the elements of the periodic system may be made radioactive by bombarding them with neutrons. The activation usually takes place by a "process of capture" as described above. The atomic nucleus which has captured a neutron is now, however, unstable and breaks up after some time with the emission of β-particles, as do many natural radioactive elements.

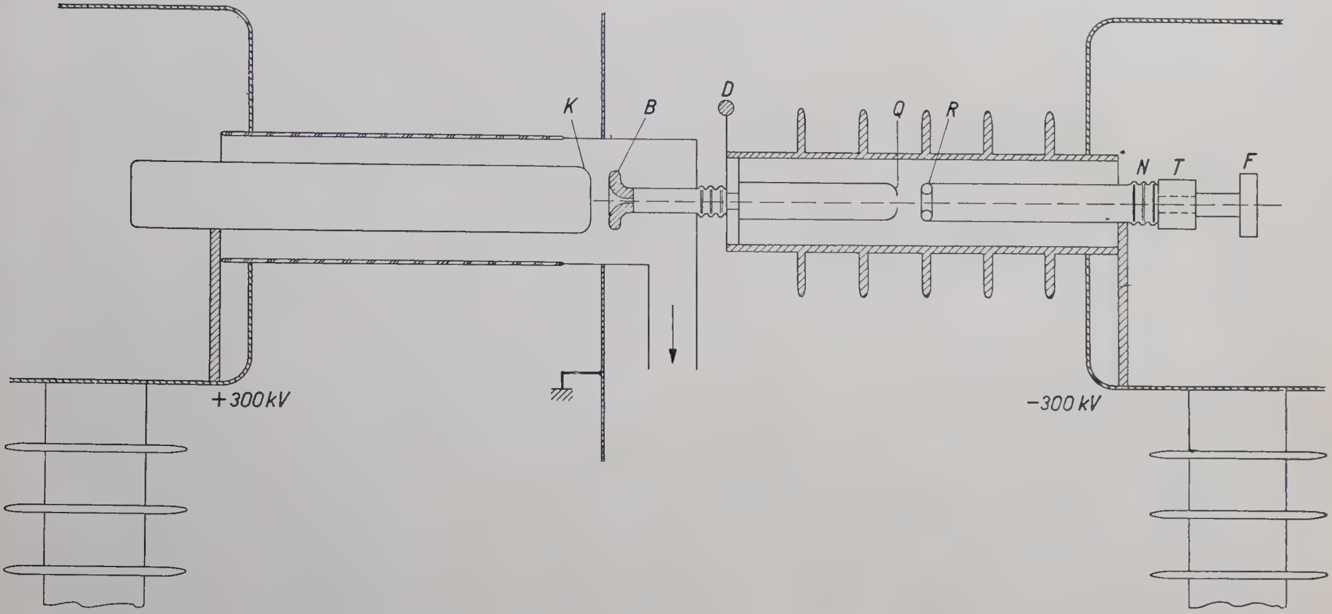

Fig. 6. Canal ray tube for 600 kV. Left-hand part as in fig. 2. To the right a second accelerating tube, where the already accelerated ions, which have passed through the earthed middle section *B-Q*, are again accelerated between *Q* and *R* with a voltage of 300 kV. The target is at a high potential (—300 kV) with respect to earth. The second tube is connected with the first by a flexible joint, and suspended at *D* in such a way that the target may be adjusted with respect to the ion beam. By means of a second flexible joint *N* different points of the target may be exposed to the ion bombardment.

Applications

In the applications of which we shall only mention those which have already been tested practically, use is made in the first place of the artificial radioactivity induced by neutrons. The amount of radioactive material which can be made with neutrons is considerable, and is for example enough for medical purposes. Compared to the natural radioactive substances the artificial ones have several advantages from the medical point of view. For example they can be introduced into the body in the form of all kinds of compounds, which is not generally possible with natural ones. The natural radioactive substances form series of equally radioactive decomposition products, some of which have long life times, so that once introduced into the body, they cause a permanent irradiation, which is not at all desired. The artificial radioactive substances, however, do not form such series, their decomposition products are no longer radioactive. If for example a patient is allowed to drink a solution of common salt which has been made radioactive, the radiation in his body will have disappeared entirely after some time.

Furthermore elements which have been rendered radioactive may be used as indicators in chemical and biological experiments. They behave chemically just like ordinary non-radioactive elements, while their presence can be detected by their radioactivity, a method which is much more sensitive and universal than chemical methods. In the realm of biology important results have already been obtained with this method. For example the distribution of phosphorus compounds throughout the body has been investigated, by feeding animals radioactive phosphorus compounds, and then finding out what parts of the body had become radioactive.

Neutrons themselves are important especially in medical applications. In experiments carried out in the Philips Laboratory by Dr. den Hoed of the cancer institute in Amsterdam it was found that neutrons have an action on organic tissues which is analogous to that of X-rays [6]). There is, however, a certain difference. While X-rays exert their influence by the ionization which they cause in the tissue by their reaction with the electrons present in it, neutrons cause an ionization due to the fact that they transfer energy to hydrogen atom nuclei present in the tissue by collision, and the latter in turn cause ionization in the tissue. In the last case the ionization is much more local, while the ionization by X-rays is more homogeneous. It may also be expected that it will be easier to irradiate more deeply lying parts with neutrons.

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[6]) The results of this investigation were communicated at the 5th International Congress of Radiology, Chicago, 13-17 Sept. 1937.

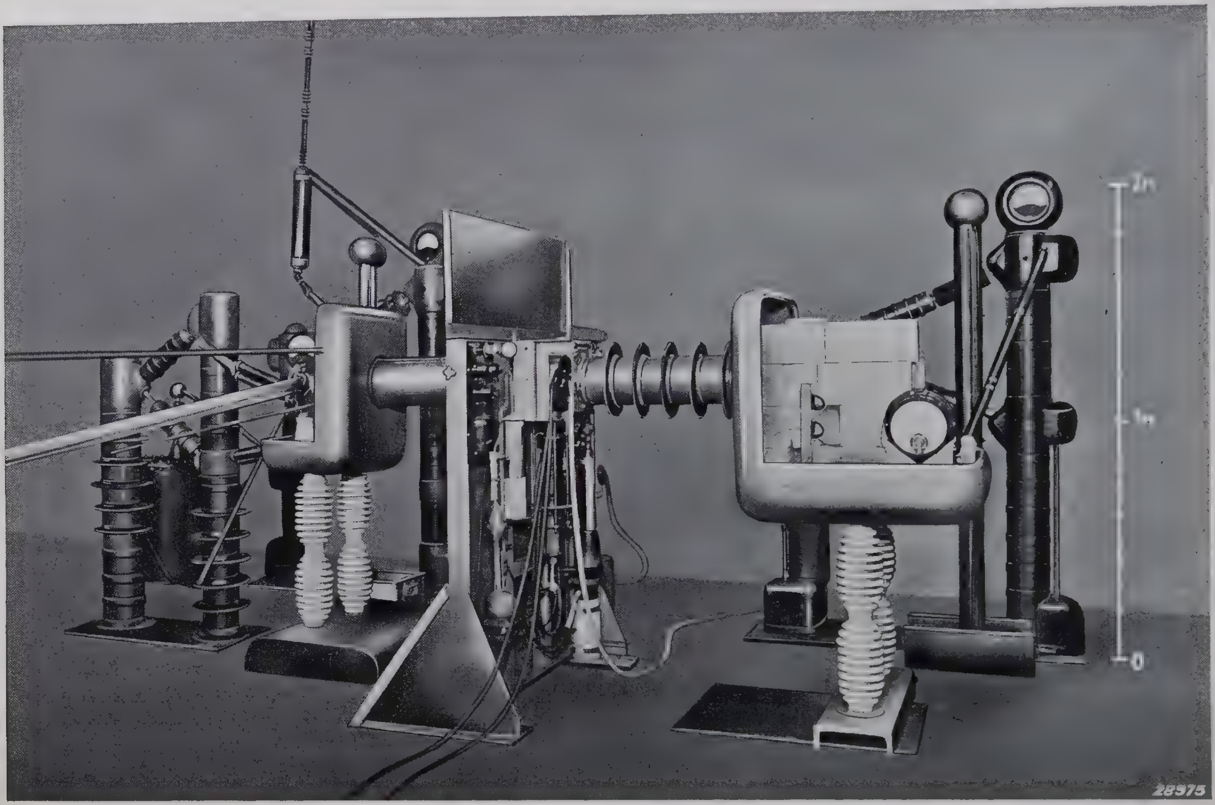

Fig. 7. Photograph of the complete neutron generator for 600 kV. The partition in the middle on which the pumping installation is mounted is earthed. To the left of it the first accelerating tube (this one was made of glass), to the right the second (of "Philite"). The neutron source proper at the right-hand end is surrounded by a number of blocks of paraffin for the protection of the worker against the neutrons. On the extreme left may be seen the source voltage generator for 50 kV, while behind the apparatus the two high-voltage generators each for 300 kV, are visible.

In experiments carried out in the Philips Laboratory in collaboration with the Kaiser Wilhelm Institut in Berlin 7), in which insects were irradiated with neutrons, it was found possible to provoke mutations, as may be done with X-rays. Here especially several differences were observed as a result of the different manner of ionization.

As may be expected after the above, it was also found from the animal tests carried out that workers must be well protected against neutrons just as against X-rays and γ-rays. On the basis of the properties mentioned above it follows that this cannot be accomplished with lead as in the case of X-rays. The best method is that of surrounding the source of neutrons with water of paraffin, about which a layer of cadmium can be added. In fig. 7 the large number of blocks of paraffin may be seen which surround the source of neutrons.

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7) N. W. Timoféeff-Ressovsky, K.G. Zimmer and F.A. Heyn, Naturwiss. **26**, 108, 1938.

APPLICATIONS OF CATHODE RAY TUBES IV.

by H. VAN SUCHTELEN.

621.317.755 : 621.385.832

The recording of diagrams

While the cathode ray tube is usually considered to be an oscillograph, it is actually in the first place an instrument which can record simultaneously and in mutually perpendicular directions two voltages (or currents). It is typically an instrument which records diagrams directly, and the diagrams only become oscillograms when one of the voltages to be recorded is connected with the time by a simple relation, and therefore provides a time base.

If is therefore quite natural that a great many applications of the cathode ray tube consist in the recording of diagrams or characteristics, and in most cases the ordinary cathode ray oscillograph is particularly adapted for these applications.

The recording of a diagram on the cathode ray tube offers several advantages over the point-by-point construction of the diagram by static measurements. The taking of meter indications point by point is undoubtedly the most accurate method in most cases. This static method can, however, not always be used.

In the first place it is impossible when overloading and consequent damage to the object to be measured might occur during static measurement. The cathode ray oscillograph makes possible much shorter but continually repeated measurements. Such rapid measurements would not be possible with a slow pointer instrument.

Very rapid measurements may also be necessary when it is a question of momentary values in a typical periodic phonomenon. The relation between current and voltage in a self-induction, for example, is dependent upon a definite speed, and can therefore never be measured statically.

A further very obvious advantage is the fact that the complete diagram is obtained so quickly. The diagram can usually be traced at a relatively arbitrary speed by the light spot, and if it is repeated regularly an impression of a stationary figure is obtained as in the case of oscillograms. This last advantage is particularly important for measurements in series production, where accuracy may to a certain extent be sacrificed to speed.

In the examples to be discussed the advantages mentioned will play a part individually and collectively. In the foregoing article of this series one case of the recording of a diagram was mentioned incidentally, namely the recording of the modulation characteristic of a transmitter. This is a typical example of a control measurement during the process of manufacture which is striking because of its simplicity and its rapidity.

Measurement of valve characteristics

In the development and manufacture of radio valves measurements of longer or shorter series of valves of the same type are often very important. It may in one case be a question of purely quantitative measurements, as in the determination of deviations in the products, or in other cases it may be more a question of qualitative determinations, or the detection of certain deviations which might occur in a few cases. In the last case the cathode ray tube is certainly the most suitable instrument.

An important characteristic of a valve is the one which gives the relation between anode current and anode voltage with the grid voltage as a parameter. In some cases a single value of this parameter is enough, in other cases a series of characteristics is required. The circuit with which such characteristics are recorded for receiver valves in the Philips Laboratory is shown in principle in *fig. 1*.

The anode circuit of the valve to be examined *X* is fed with a voltage which varies periodically between zero and its maximum value. This voltage

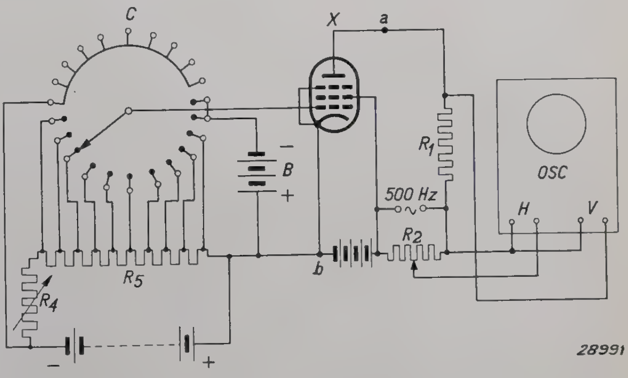

Fig. 1. Circuit for the recording of diagrams. The oscillogram shows the anode current of the valve X as a function of the anode voltage. By means of the rotating commutator C a number of different control grid voltages are allowed to act during each revolution ($^1/_{25}$ sec), so that a series of curves appears on the screen. One of the grid biases (-6 volts) is not taken from the resistance R_4, but it is supplied by the battery B. This is connected with two of the contacts. Because of this the line for -6 volts appears stronger than the other curves in fig. 2.

is obtained by the connection in series of a direct voltage and an alternating voltage of 500 cycles and of the same amplitude. In the cathode ray tube a horizontal deviation must be obtained which is proportional to the variation in anode voltage. For this purpose a potentiometer R_2 is connected over the alternating voltage, which reduces the value used to a figure suitable for the tube. The voltage tapped off is led to the terminals of the plates for horizontal deflection of an ordinary oscillograph (terminals H in fig. 1). The Philips cathode ray oscillograph G.M. 3152 is also provided with such a connection. The anode current flows through the measuring resistance R_1 and the fairly low voltage which occurs over this resistance is fed to the built-in oscillograph amplifier V. In this way a vertical deviation is obtained which is proportional to the current.

In this simple manner a single diagram can already be recorded with a given screen grid and control grid voltage.

The way in which a series of characteristics is recorded simultaneously is also indicated in fig. 1. By means of a rapidly rotating commutator the control grid is momentarily connected to the successive taps of a potentiometer R_5. The difference in potential between successive contacts can be set at 1, 2, 3 volts, etc. by means of a series resistance. One would be inclined to suppose that the commutator should be exactly synchronized with the frequency of the anode alternating voltage. This is, however, unnecessary. Without the slighest difficulty it is possible to pass from one characteristic to the following one, even before the first one has been completed. The part lacking is then traced during the next rotation of the commutator Since the frequency at which the commutator rotates, and therefore at which the whole series of characteristics is repeated, is of the order of 25 c/s an impression is given of a single picture with no interruptions.

The commutator is composed of 22 contact-lamina. 10 of these are connected to the successive taps of R_5. Series of 10 characteristics are therefore recorded. For the first characteristic $V_g = 0$; all the other curves are recorded with negative grid bias. Two lamina are connected to a calibration voltage of, for instance, —6 volts. Because of this two characteristics are always traced one over the other for $V_g = -6$ volts, independent of the setting of R_4. This line is noticeable because of its greater brilliance. It is now possible to adjust R_4 in such a way that the second, third, fourth, etc. characteristic of the series coincides with that for $V_g = -6$ volts. Then it is known that V_g changes by the amounts 6, 3 or 2 volts, respectively.

Finally the other 10 laminae of the commutator are connected to a fairly high negative voltage, so that the anode current is completely suppressed during half of every revolution. This is necessary for the following reason. The anode voltage reaches a very low value for some time during the measurement (it falls as far as zero.) In pentodes an abnormally high screen grid current occurs at these low anode voltages. In order to protect the screen grid from excessive heating the cathode current is suppressed for some time during each measurement. This is an example of the first advantage mentioned above to be derived from the use of the cathode ray tube.

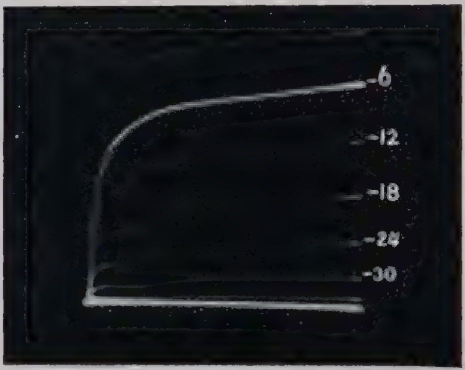

Fig. 2. Diagram of the anode current as a function of the anode voltage recorded with the help of the circuit shown in fig. 1. The abscissae run from 0 to 500 volts, the ordinates from 0 to 200 mA.

Fig. 2 shows a series of characteristics recorded on a test model of a pentode end valve. The second curve from the top corresponding to $V_g = -6$ volts is noticeable because of its intensity. The grid voltage was apparently varied by steps of 6 volts. Furthermore in the bends of the third, fourth and fifth characteristics an irregularity may be seen which indicates secondary emission of the anode. This irregularity is the weak counterpart of the much greater dip which occurs with tetrodes (see Philips techn. Rev. 3, 215, July 1938).

When the resistance R_1 in fig. 1 is added to the screen grid circuit of the valve to be examined, the characteristics are obtained of the screen grid current as a function of the anode voltage (*fig. 3*). In this figure also the guiding line for —6 volts may again be recognized. Furthermore irregularities in the curve may also be seen which are due to the secondary emission of the anode; for every fall in the anode current due to secondary emission there is a corresponding rise in the screen grid current.

Finally it may here be seen that relatively high currents flow when the anode voltage is low. These currents would overload the screen grid in static measurement.

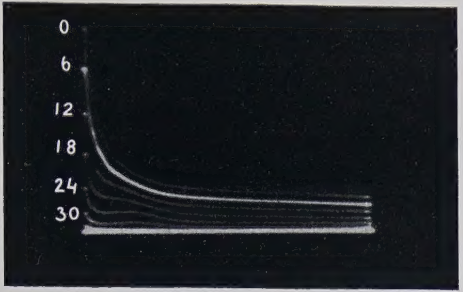

Fig. 3. Diagram of the screen grid current as a function of anode voltage, recorded with the same valve as in fig. 2, and on the same scale.

The measurement of a hysteresis loop

Another example of a measurement in which a dynamic method gives a certain simplification compared with static measurement is the determination of the induction B in a magnetic material, *i.e.* the measurement of a hysteresis loop. A ballistic galvanometer is usually used for this, and the induction impulse occurring in a secondary winding is measured when the magnetizing field is interrupted by switching off the current in the primary winding (see J. J. Went, Philips techn. Rev. 2, 84, 1937). A secondary voltage occurs with momentary values proportional to $\mathrm{d}B/\mathrm{d}t$. When the magnetization is not changed suddenly, but periodically, the induced voltages can be integrated very simply electrically, instead of mechanically as in the ballistic galvanometer, so that voltages proportional to B occur.

The principle of the circuit with which this is done is shown in *fig. 4*. A closed ring is made of the test material in the usual way and two windings are laid around it. The primary winding S_1 is supplied with alternating voltage over a resistance R_1. A voltage therefore occurs over this resistance which is proportional to the number of ampere turns, and this voltage can be led directly to the terminals H for horizontal deflection.

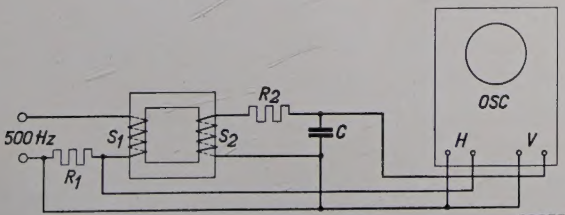

Fig. 4. Circuit for recording hysteresis loops. The voltage at the coil S_2 is proportional to $\mathrm{d}B/\mathrm{d}t$. If the impedance of C is small with respect to R_2 the voltage at C is proportional to the momentary value of B.

As mentioned above the following voltage occurs over the secondary winding S_2:

$$v_2 = \text{const.}\ \frac{\mathrm{d}B}{\mathrm{d}t}\,.$$

The combination of resistance R_2 and capacity C is connected with this winding. When care is taken that the voltage at C is very small compared with v_2, it may be assumed that a current flows through R_2 and C which has a momentary value of:

$$i_2 = \frac{v_2}{R_2} = \frac{\text{const}}{R_2}\,\frac{\mathrm{d}B}{\mathrm{d}t}\,.$$

The voltage at C thereby becomes:

$$v_C = \frac{1}{C}\int i_2\,\mathrm{d}t = \frac{\text{const}}{R_2\,C}\,B.$$

The voltage at C is therefore actually a measure of B. This voltage must be small with respect to that at S_2, while the latter will not for practical reasons be much higher than for instance 100 volts. From this it follows that the oscillograph amplifier must be connected between C and the plates for vertical deflection.

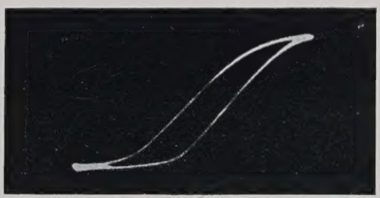

Fig. 5. Hysteresis loop recorded by means of a circuit like that of fig. 4

Fairly heavy demands as to phase fidelity are made of the oscillograph amplifier in this and in the previous case. In general a constant amplification over a very wide frequency range is the primary requirement in the case of an oscillograph. Over the greater part of this range the phase fidelity is also practically perfect. At the boundaries, however, inevitable small phase shifts occur. Since very slight shifts are very disturbing in the reproduction of diagrams (double lines), in the two cases described the measurements were carried out at a frequency of 500 c/s instead of at the usual 50 c/s since upon amplification of these low frequencies phase shifts would already occur.

A hysteresis loop recorded according to fig. 4 is reproduced in *fig. 5*.

Measurement of frequency with the cathode ray tube

A type of measurement which is connected with the two preceding ones to only a certain extent is the comparison of unknown frequencies with a standard frequency, *i.e.* for example a method for the measuring generators which are used in acoustic measurements.

The comparison of the frequency of a generator to be calibrated with a standard frequency is often done by ear, when the frequency to be determined differs from the standard by a whole number of octaves. This method may be very accurate, because of the fact that slight deviations can be detected due to the occurrence of beats. When, however, one of the two oscillations contains overtones, it becomes difficult to determine the number of octaves difference. Similarly the comparison by ear is not possible with great accuracy when the frequency to be calibrated does not differ from the standard frequency by a whole number of octaves.

By supplying two alternating voltages of different frequency to the two sets of plates of a cathode ray tube a very accurate comparison is possible. This is also true in the case of quite arbitrary relations between the frequencies, as long as they may be expressed in the form of a ratio of two whole numbers which are not too large.

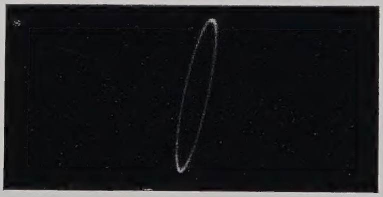

Fig. 6. If sinusoidal alternating voltages of the same frequency but of different phase are supplied to the horizontal and vertical deflection plates of a cathode ray tube, the resulting figure is an ellipse.

When voltages whose frequencies are related as whole numbers, are supplied to the plates, a stationary figure results. If the frequencies are the same, a straight line or an ellipse is obtained according to the phase relation of the voltages (*fig. 6*). With other ratios of frequencies the so-called Lissajous figures are obtained. *Fig. 7* gives an example of one of these.

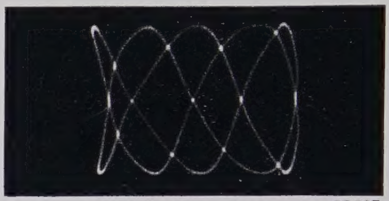

Fig. 7. Lissajous figure which occurs when the frequencies of the vertical and horizontal deflecting voltages are in the ratio 5/2.

The ratio of the frequencies may be deduced from the last figure in the following way. In the time during which the figure is completely traced five upper peaks have been reached in the vertical direction, therefore there have been five periods. In the horizontal direction the left (or right) side of the figure has been reached twice, therefore two periods have elapsed. The frequency of the vertical oscillation was therefore the higher, and was apparently $^5/_2$ of that of the horizontal oscillation. As soon as the ratio of the frequencies deviates slightly from $^5/_2$, the successive figures no longer exactly coincide, and the figure appears to move. Because of this it is possible to measure frequencies very accurately.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS GLOEILAMPENFABRIEKEN

1309: K. S. Knol, M. J. O. Strutt and A. van der Ziel: On the motion of electrons in an alternating electric field (Physica **5**, 325 - 334, May 1938).

With a high vacuum electron tube which consists of a cathode, two grids and an anode, by applying the correct alternating voltages of high-frequency and direct voltages, it is possible to cause a part of the electrons to attain a higher speed than that which corresponds to the momentary value of the electric potential at the point where the electron is situated. From the equations of motion an expression is derived for the kinetic energy of the electrons. This expression is discussed and applied to special cases. Upon comparison with the results of measurements it is found to give satisfactory agreement. As an application a new method is described of rectifying an alternating voltage of high frequency.

1310: A. van Kreveld and J. A. M. van Liempt: Measurements on dark-room illumination (Physica **5**, 345 - 373, May 1938).

The conditions are examined which must be satisfied by dark-room lamps for the successful development of negatives. The sensitivity of the eye to contracts was determined for different colours from green to dark red under the conditions prevailing in a dark-room. The sensitivity of different photographic emulsions was measured for the whole visible spectrum. From these measurements the most satisfactory kind of light for orthochromatic and panchromatic emulsions was determined. Finally the energy was calculated of a dark-room lamp which caused an inadmissible decrease in photographic contrast, from which the quality of any given dark-room lamp follows.

1311: R. Houwink: The yield value (Second report on viscosity and plasticity; Verh. kon. Ned. Akad. Wet. A'dam, afd. Natuurk. 1e Sect. **16**, No. 4, 185 - 240, 1938).

This report, which was given before the Kon. Ned. Akademie van Wetenschappen, deals with the yield value, by which is meant the lowest shearing stress at which a substance undergoes permanent deformation and therefore begins to behave non-elastically. For several simple cases diagrams are given of the way in which the deformation depends upon the shearing stress, and the experimental observation of the yield value is discussed as well as the conditions under which "flow" may occur. A model is described to illustrate the phenomena of plastic deformation exhibited by crystalline substances. The dependence of the yield value on temperature and on the degree and rate of deformation is discussed. The significance of migrations of individual atoms, ions and molecules is dealt with, and conclusions are drawn about the plastic behaviour and the yield value of crystalline substances. The yield value of amorphous substances and suspensions is then dealt with, while finally the relation between yield value and coefficient of viscosity is discussed.

1312: M. J. O. Strutt and A. van der Ziel: Messungen der komplexen Steilheit moderner Mehrgitterröhren im Kurzwellengebiet (El. Nachr. Techn. **15**, 103 - 111, April 1938).

A brief explanation is given of the influence of a phase shift between grid voltage and anode current in receiving valves on the limit of stability of an amplifier stage and in receiver valves on the excitation of alternating voltages. The measuring arrangement and the sources of error are discussed in the measurement of the complex slope of valves with several grids in the short wave region. The method of measurement resembles that of Llewellyn. The results of the measurement for high frequency pentodes are given and compared with calculations, with which they are found to give satisfactory agreement. Measuring results on hexodes are also briefly discussed. Measurements of the phase shift of the slope were also carried out on amplifier valves based on secondary emission, and the results agree satisfactorily with the calculations. The effect of a super secondary emission according to Malter is dealt with briefly and illustrated by measurements on the decrease of slope in the high-frequency region. Finally the influence is discussed of the phase shift in the slope on the frequency dependence of the characteristic admittances of the tubes, whereby it is found that the formulae previously given by the writers remain correct in the approximation in question.

1313: J. Bergmans: Light reflection by road surfaces (Diss. Delft 1938; 111 p.).

The coefficient of brightness is an important quantity in the characterization of the nature of light reflection on road surfaces. By this term is meant the quotient of the brightness in the direction of vision divided by the intensity of illumination of the surface viewed. An arrangement is discussed for the measurement of coefficients of brightness of road surfaces and the results obtained with it are given. Conclusions are drawn as to the construction of road surfaces with a profile such that water is drained away so rapidly that even during a shower they never or scarcely ever become inundated. In order to obtain a more uniform brightness of road surface it is finally proposed to place the sources of light higher, which causes only a slight decrease in the average brightness.

1314: J. H. de Boer: The electrons in non-metals in their relation to thermo-electric properties (Ingenieur **53,** E26 - 31, June 1938).

The conduction of heat and electricity by non-conductors is discussed in relation to the variation of potential in the crystal lattices concerned, in which there may be electrons with different energy contents while other energy contents are „forbidden".

1315: J. E. de Graaf: X-ray interpretation in the electric welding of steel (Weld. Industr. **6,** 41 - 45 and 93 - 96, March and April 1938).

A survey is given of defects in welding which may be detected by X-ray examination. It is found that the pictures obtained are often sufficiently characteristic to make possible the detection of the cause of the defect as well (*cf.* Philips techn. Rev. **3,** 93, 1938).

1316: R. Vermeulen: The Philips-Miller method of recording sound (J. Soc. Motion Pict. **30,** 680 - 693, June 1938).

In this article a survey is given of the Philips-Miller system of sound recording, for which we may refer to the series of articles on this subject in the first volume of this periodical (Philips techn. Rev. **1,** 107, 135, 211, and 230, 1936).

1317: M. J. O. Strutt: Electron transit time effects in multigrid valves. Measurements on short waves. (Wirel. Eng. **15,** 315 - 321, June 1938).

The electron coupling in octodes for frequency transformation can be represented by a unilateral negative capacitance of the oscillator grid (1st grid) to the input grid (4th grid), at least when the phase shift caused by the electron transit time may be neglected. If this phase shift does play a part a unilateral negative resistance in parallel with this negative capacitance must also be taken into account. The transit time can be calculated from measurements of this negative resistance and capacitance. These measurements were carried out at a wave length of 31 metres; their results are found to be in satisfactory agreement with the roughly calculated transit time. Moreover the slope was measured between the oscillator grid and the oscillator anode of an octode, and it was found that a phase shift of about 60° occurs in it at a wave length of 9 m due to the transit time. The calculated transit times agree quite well with the values measured. In addition there is a discussion of the transit time current which, in the form of a low direct current, flows to the first grid of a tetrode with several volts negative bias, while the anode is connected in series with a negative bias and a high-frequency generator, and the screen grid is positive. Finally it is indicated, how this transit time current can be used for a new kind of detection.

1318: Balth. van der Pol and H. Bremmer: Ergebnisse einer Theorie über die Fortpflanzung elektro-magnetischer Wellen über eine Kugel endlicher Leitfähigkeit (Hochfrequenztechn. u. Elektroakust. **51,** 181 - 188, June 1938).

This is a summarizing review of the theory of the diffraction of electromagnetic waves around a sphere which was dealt with in detail in Phil. Mag. **24,** 141 and 825, 1937 (*cf.* **1264**) and in Phil. Mag. **25,** 817, 1938 (*cf.* **1338**). Formulae are given from which the field of a transmitter can be determined in a simple way. To these are added a complete set of practical curves for the field at the surface of the earth when the transmitter is on the ground, not only for propagation over the sea but also over land of average conductivity. These curves relate to the whole wave length range from 1 m to 20 km.

In Sept. 1938 appeared:

Philips Transm. News **5,** no. 3:

C. G. A. von Lindern and G. de Vries: Decimetre wave radiolink between Eindhoven and Nimeguen.

A new Philips Studio equipment.

Tj. Douma and P. Zijlstra: The use of the cathode ray oscillograph for the determination of transmitting valve characteristics that cannot be measured in the ordinary way.